Mark Begich, Mayor

# Fecal Coliform in Anchorage Streams: Sources and Transport Processes

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MUNICIPALITY OF ANCHORAGE
WATERSHED MANAGEMENT SERVICES

SEPTEMBER 2003

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Office of Planning, Development
& Public Works

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**September 2003**

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| °F | degrees Fehrenheit |
| µm | micrometer |
| ADF&G | Alaska Department of Fish and Game |
| col/100 ml | colonies per 100 milliliters |
| CSO | combined sewer outfalls |
| EOP | end-of-pipe |
| EPA | U.S. Environmental Protection Agency |
| LID | low impact development |
| MOA | Municipality of Anchorage |
| NPDES | National Pollutant Discharge and Elimination System |
| TMDL | total maximum daily leads |
| USGS | U.S. Geological Survey |
| WQM | Water Quality Management |

# SUMMARY

Fecal coliform, as a surrogate for the presence of biogenic contaminants, has been measured at elevated concentrations in a number of Anchorage receiving waters. During summer months fecal coliform concentrations frequently exceed State of Alaska water quality standards for drinking water and contact recreation. As a result, eight streams and five lakes within the Municipality of Anchorage (MOA) have been designated as "water quality impaired" for this pollutant by the State of Alaska Department of Environmental Conservation (ADEC, 1996). Although Federal law requires that the State identify implementation measures to control impairments (40 Code of Federal Regulations [CFR] 130.6(c)(6)), much of the responsibility to assess and mitigate these impacts will undoubtedly be assigned to the MOA as the owner of storm drainage systems operated under a National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System Permit to discharge storm water.

## FECAL COLIFORM SOURCES AND TRANSPORT PROCESSES

Selection and implementation of effective control and monitoring options will require a sound understanding of the source of the fecal coliform contaminants found in Anchorage receiving waters and their associated risk to humans. Source and risk information will also be important in balancing the costs and benefits of implementing control options. To address these needs, this document summarizes the character of the source of the fecal coliform contaminants measured in Anchorage streams and lakes. The risk these contaminants may pose to the health of Anchorage residents is assessed in a separate document.

Although many sources have been postulated to account for the elevated fecal coliform concentrations observed in Anchorage receiving waters, only a few of these are significant contributors to the problem. However, because of widespread speculation about the source of the fecal contamination in Anchorage streams, it is important as a first step to point out those sources that are *least* likely to contribute significantly:

- Municipal community piped sanitary sewer systems are not a widespread source of fecal coliform in local streams. Anchorage has never operated combined sewer outfalls (CSOs), and intensive sewer system investigations in the past have rarely discovered cross-connects to the separate storm drain piping.
- On-site waste water disposal systems are not a widespread source of fecal coliform in streams. The MOA closely monitors design of on-site installations and past investigations suggest fecal coliform contamination from these systems is not readily mobilized to receiving waters. However, additional constraints in siting these facilities on sensitive landforms (e.g., glacial paleochannels and high-permeability ice contact deposits) may be warranted.
- Street surfaces (and the materials applied to them) are not significant sources of fecal coliform in Anchorage. However, gutters and storm drain systems are important transport routes for fecal colliform originating from other sources, particularly from lawns and garbage collection.

- Fecal coliform growth within storm drainage systems is not a significant source of fecal coliform in Anchorage. However, deposition and scour from treatment devices installed along storm drain pipes and ditches can contribute to significant short-term variability in coliform loading in storm water discharges.

Based on analysis of storm water runoff and flood flow transport mechanisms (and lack of evidence for any other widespread sources), MOA investigators attribute the primary biogenic source of the persistent elevated fecal coliform concentrations observed in Anchorage streams to animal (non-human) or plant origin. Some smaller, but still significant, human contribution to stream fecal contamination might also exist, but appears primarily related to garbage exposed to storm water runoff. Warm-blooded animal sources include domestic pets (particularly cats and dogs) and wild animals (particularly terrestrial and aquatic birds, shrews, rabbits, rodents, foxes, coyotes, wolves, bears, and moose).

Analysis of local data further indicates that elevated fecal coliform concentrations are complexly related both to distributions of fecal matter from animal (non-human) sources and to idiosyncratic transport processes within local storm drainage systems and the streams themselves. Patterns in fecal coliform concentrations in receiving waters show that contaminants from upland sources are mobilized by precipitation, then transported in storm water runoff to receiving waters. Domestic and wild animals, particularly moose, bear, swimming freshwater birds, and shorebirds (including ducks, geese, and gulls), add directly to the total fecal coliform load carried by the stream. Finally, fecal coliform concentrations are further modified by intermittent and seasonal deposition and scour of fine, coliform-carrying sediment as storm water or stream flows pass through treatment devices or impounded stream reaches. Critical source and transport factors can be summarized as follows:

- Elevated fecal coliform concentrations in Anchorage streams occur on a summer seasonal basis, associated predominantly with increasing rainfall and rainfall runoff. Conversely, fecal coliform concentrations are significantly depressed during the winter, when baseflow conditions predominate.
- Elevated fecal coliform concentrations in Anchorage streams are directly responsive to runoff-producing snowmelt and precipitation events and to increased seasonal stream flows. However, the degree of this response is complexly related to the character of watershed landuses, types of storm drainage conveyances, and the degree of stream modification.
- Primary contaminant sources include domestic pets and wild animals, although, to an unknown but potentially significant degree, human contaminants might also be mobilized from exposed garbage. In riparian areas, wild animals (particularly geese) are a primary source of fecal contamination, although domestic animals might contribute where landscaped parks and trails adjoin receiving waters. Pets, and particularly outdoor dog holding pens of all sizes, are likely the primary source of widespread fecal contamination in Anchorage urban storm water. However, areas of concentrated domestic animal activity (e.g., dog parks and equestrian trails) and large animal holding areas (stables, kennels, and outdoor zoos) may be significant point sources of fecal contamination.

- Fecal coliform loading is high in storm water runoff originating from landscaped surfaces located in densely urbanized areas drained by curb and gutter piped systems. Although Anchorage data indicates the coliform loading in this runoff originates from adjacent landuses and not from the street gutter materials, fine street sediments do provide protective adsorption sites for the coliform bacteria and significantly affect its fate and transport in storm water and stream flow.
- Fecal coliform loading in storm water from Anchorage rural residential areas is smaller and occurs over a narrower seasonal time period than contaminant loading in runoff from more densely urbanized areas. This is due to the reduced runoff volume typical of Anchorage rural land development. Although the amount of source fecal material might be the same as at more densely urbanized areas, ditched storm water conveyances typical of rural areas significantly reduce rainfall runoff as a result of increased infiltration.
- Fecal coliform stored in fine-grained streambed sediments are an important element in the timing and magnitude of the observed elevated concentrations of fecal contaminants in Anchorage stream flow. Periodic settlement and scour of fine streambed sediments carrying fecal coliform is particularly aggravated by ill-advised stream channel modifications and washoff of fine grit used to improve winter street traction.

## FECAL COLIFORM CONTROLS AND PERFORMANCE MONITORING

Functional control options for fecal coliform in Anchorage are intimately tied to the characteristics of local basins and their storm water drainage systems, and to the channel characteristics of the receiving streams. Thus, effective control strategies must differentiate between densely urbanized areas drained by curb and gutter piped systems, and rural areas drained predominantly by ditches. However, in both cases, source control of storm water runoff hydraulics will be a primary factor in controlling fecal coliform contamination. Stream channel and riparian zone management must also be considered as central program elements. The effects of pollutant concentration during settlement, and subsequent pulse elevation in water column concentrations by their re-suspension during flood flows, will aggravate the in-stream problem and might mask positive effects of landuse controls.

Ultimately, controls should focus on ‘leverage’ points in the entire fecal coliform transport system, including management of contaminant sources, storm water hydraulics, and stream channel and riparian zone quality. Specific management practices and issues to consider in such a program should include:

- Providing public education, including signage, describing storm water system uses, management, and impacts.
- Improving controls for curbside garbage pickup practices.
- Implementing and enforcing setback and storm water controls for all animal holding areas, including formal design requirements for all large-scale facilities.
- Controlling urban wildfowl populations, including required practices and controls for all large lawn landscapes.
- Restricting use of on-site drainfield systems for select landforms.

- Implementing on-site storm water detention and infiltration standards (Low-Impact Development or LID) for all commercial and residential development and re-development.
- Optimizing use of ditch and swale designs for storm water drainage systems, including required application of these structures to all 'headwater' streets.
- Implementing requirements for installation of storm water runoff sheetflow controls ('yard breaks') for all driveways, and yards, and other landscaping served by curb and gutter piped drainage systems.
- Optimizing street sweeping practices and schedules to remove fine particulates for all curb and gutter road systems.
- Optimizing storm water hydraulic connection to natural wetlands, or to detention and water quality treatment basins.
- Implementing riparian zone conservation and recovery programs (including implementation of function-based setback standards), and restricting stream channel ditching and armoring.
- Implementing non-obstructive stream crossing design standards and retrofit of existing constricted stream crossings.

Finally, accurate monitoring of short-term performance of fecal coliform controls through stream or storm water quality sampling is not an economically viable option. This is due to the extreme variability in fecal coliform concentrations in both storm water runoff and stream flow. Sampling storm water quality to measure control effectiveness, while accounting for system variability, will not be economically feasible. Monitoring control performance through collection of stream water or sediment quality measurements will be feasible only with implementation of carefully designed, long-term (3 to 6 years) programs. Otherwise, short-term performance (1 to 2 years) will be best measured by assessing the extent to which selected best management practices are installed.

# PART 1 INTRODUCTION

## 1.1 MANAGEMENT ISSUE

The State of Alaska specifies fecal coliform concentrations at which receiving waters are protected for various uses and has generally set maximum concentrations for drinking water and secondary contact recreation uses at 20 and 200 colonies per 100 milliliters (col/100 ml), respectively (ADEC, 2003a). Substantial data exists suggesting that fecal coliform concentrations in urban Anchorage streams exceed these standards on a seasonal basis, particularly in association with stream floodflow conditions. Based on these data, and in accordance with Section 303(d) of the federal Clean Water Act, the State has currently designated eight streams and five lakes within the MOA as being water quality-limited for this pollutant (ADEC, 1996).

Seven of the eight Anchorage streams designated as water quality impaired have been scheduled for development of total maximum daily loads (TMDLs) for fecal coliform by 2003. At the date of the preparation of this document, draft TMDL analyses have been prepared for five of these streams (ADEC, 2003b, c, d, e, and f) Under federal law, the State is required to incorporate these analyses into its Water Quality Management (WQM) Plan (40 CFR 130.6). The WQM Plan directs implementation of specific controls required to achieve the TMDL, including waste load allocation controls (for point sources) and load allocation controls (for non-point sources). Finally, the State is required to report appropriate monitoring data to the U.S. Environmental Protection Agency (EPA) to determine if water quality standards have been attained or are no longer threatened (USEPA, 1991).

How pollutant control responsibility is apportioned to point source types versus non-point source types is broadly left to the discretion of the TMDL developer and the local stakeholders (USEPA, 2001, p 7-1). Apportionment of pollutant load control required of each source type can hinge significantly on the fractional pollutant load each source type contributes to the overall problem, and the degree to which the source types are amenable to practical control. Obviously, a sound knowledge of the sources of the fecal coliform measured in streams is fundamental to selection and implementation of an effective and practicable control program. Further, detailed knowledge of types and distribution (both spatial and temporal) of the fecal coliform sources will support risk assessments that can help focus source control priorities. Finally, meaningful measurement (monitoring) of the performance of controls that are ultimately put in place will also depend on a reasonably accurate understanding of the source, fate and transport of these pollutants.

Identification of practicable and effective controls for fecal coliform sources will be particularly important in Anchorage. The MOA operates its storm drainage systems through an NPDES Municipal Separate Storm Sewer System Permit to discharge storm water (USEPA, 1998). Under this permit, all MOA storm water conveyances (both piped and ditched) are defined and regulated as 'point sources.' The EPA's TMDL guidance requires that where there are no reasonable assurances that 'non-point sources' can be reduced, the entire load reduction must be assigned to 'point sources' (USEPA, 1991, p 13).

In the case of Anchorage, such a control apportionment would weigh heavily towards the MOA storm water system as a NPDES-permitted operation, potentially placing the MOA in a difficult position. Because municipal storm drainage is defined in federal law as a 'point source' system, it would be subject to absolute requirements for pollutant control under the TMDL process. However, in reality, the MOA storm drainage systems function as 'non-point source' systems (and thus are subject to the same uncertainty and variability in control performance that other 'non-point sources' exhibit). In short, the MOA's storm water systems could be required to meet stringent water quality requirements as a result of its legal-definition as a 'point source' that may not be practicably achievable because of its real 'non-point source' nature. This is a bit of a 'Catch 22' in federal storm water law that has yet to be resolved by Congress.

In the meantime, it is clearly in the MOA's best interest to carefully define the most probable sources of the fecal coliform contamination that are driving the current TMDL process in Anchorage. This information can be used to help balance any proposed apportionment of TMDL-driven controls against a 'maximum extent practicable' implementation measure, an upper performance limitation placed by Congress on municipal storm water systems.

## 1.2 PURPOSE AND LIMITATIONS

The purpose of this document is to provide a summary of the current MOA understanding of *sources and fates* of fecal coliform as measured in Anchorage storm water discharges and receiving waters. This white paper is intended to be an interpretive technical summary based on local data, both recent and historic, and on related national science research. This white paper's immediate use is in support of analysis of risk to human health from fecal coliform in Anchorage storm water and receiving waters. In addition, the information summarized in this document is also intended as a technical guide in the selection and prioritization of effective and practicable control strategies for pathogens mobilized and transported in Anchorage storm water.

This document specifically addresses the probable biologic sources of the elevated fecal coliform contaminants observed in Anchorage waters, as assessed through review of local sampling results, interpretations, and national science. The paper is organized to describe the MOA's current understanding of: impacts to receiving waters from fecal contaminants; transport and storm water runoff systems and processes as they relate to probable fecal contaminant sources; and fecal coliform sources and their spatial and temporal relationship to transport in storm water. Characterization of Anchorage receiving water pathogen quality is supported by an annotated bibliography of relevant local studies and data sources. Descriptions of storm water drainage and stream systems reflect both past investigations and significant detailed mapping and study recently completed by MOA staff and contractors.

Contaminant source analysis in this document is based both on recent detailed investigations and careful review of past investigations. Because fecal coliform has typically been measured in Anchorage as a surrogate for human-specific pathogens transported in MOA storm water, this white paper focuses particularly on the human versus animal origins of fecal coliform and their association with storm water runoff. In addition, the magnitude and spatial and temporal distribution characteristics of fecal coliform contaminant sources and probable transport routes and mechanisms are also addressed in some detail. Finally, the implications these source and transport characteristics have for applications of controls and control monitoring are summarized. The broader question of risk to human health that these sources may imply will be addressed in a separate document.

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# PART 2 FECAL COLIFORM IN ANCHORAGE RECEIVING WATERS

The results of decades of water quality sampling of streams within the Anchorage area suggests that State standards for fecal coliform in these receiving waters are frequently and regularly exceeded (MOA, 1992a, Part 1, Appendices B and C). Although few data have been collected that can be rigorously applied to test compliance with State standards of any Anchorage receiving waters, the abundance and consistency of sampling results clearly indicate that fecal coliform standards are, in fact, regularly exceeded within many Anchorage urban streams.

More important to assessing the source of elevated fecal coliform concentrations in Anchorage, however, is the consistent temporal pattern in exceedances that these data describe. Repeating seasonal patterns are apparent in fecal coliform data collected by the MOA Department of Health and Human Services over a 4-year period at select stations on Anchorage streams through the Water Quality Fecal Coliform Program. Representative of these data are the analytical results of samples collected from Chester Creek from 1988 to 1991 at its Arctic Boulevard crossing, transformed as the log mean moving average of each five consecutive samples and plotted on Figure 1 (MOA, 1992a, Part 1, p 4-17). For reference, Anchorage precipitation as a 7-day average and the average daily temperature range is plotted beneath the seasonal fecal coliform concentrations (WMS, 1999b).

Inspection of Figure 1 shows that fecal coliform concentrations are consistently low in winter months (when surface runoff flows occur only as the result of unusual mid-winter thaws). Stream fecal coliform concentrations at winter baseflow conditions range from about 10 to $10^2$ col/100 ml. A modest spike in concentrations occurs in late March and April, coinciding with urban snowmelt runoff. In late April and May after urban snowmelt has ended but when rainfall remains light, fecal coliform concentrations continue to reflect those typical of winter baseflow conditions. By mid-June, however, a rapid rise in fecal coliform concentration begins, coinciding with the beginning of the seasonal rainy cycle at Anchorage. A pronounced, seasonal peak typically occurs in August, with peak fecal coliform concentrations on the order of $10^3$ col/100 ml, and generally coinciding with stream flood flow peaks. Concentrations begin to fall off by late summer, dropping steadily to those typical of winter baseflow conditions by early October. The late-summer/early-fall decline in fecal coliform concentrations is in marked contrast to a rainfall pattern that is still at its peak late in September and October.

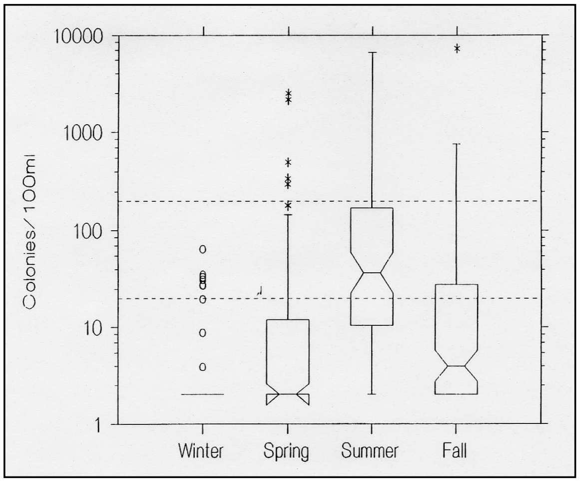

**Figure 2.** Seasonal Fecal Coliform Patterns in Area Lakes

This overall seasonal pattern is strongly indicated in lake water quality data, as well as in the stream data (Figure 2). The presence of a distinctive pattern in lake data is particularly meaningful because the reservoir effect of lakes would be expected to mask minor or short-term seasonal patterns in water quality (MOA, 1992a, Appendix C).

In summary, fecal coliform concentrations in Anchorage streams have the following distinctive seasonal patterns:

- At winter baseflow, when little surface runoff occurs, fecal coliform concentrations are low (about $1x10^1$ to $1x10^2$ col/100 ml).
- Concentrations rise to a low peak coincident with urban snowmelt ($2x10^2$ to $5x10^2$ col/100 ml).
- Early summer concentrations return to low levels, similar to winter baseflow concentrations, and coincide with seasonal light precipitation patterns.
- Middle-summer concentrations increase sharply, coinciding strongly with the beginning of increasing seasonal rainfall.
- Peak concentrations ($1x10^3$ to $3x10^3$ col/100 ml), coinciding with stream flood flows, occur in late-summer, just as rainfall patterns begin to reach seasonal peaks.
- Concentrations decline in late-summer and fall, but with a timing that significantly precedes the seasonal drop in average daily precipitation.

Thus, patterns in elevated fecal coliform concentrations in Anchorage streams show a very robust and direct correlation both to storm water runoff and peak stream flows. Conversely, at seasonal base flow conditions (winter and early summer) fecal coliform concentrations are relatively low. This leads to two very basic conclusions that are critical to identifying the predominant sources of fecal coliform contaminants measured in Anchorage stream flows:

- The predominant source materials of the observed elevated fecal coliform concentrations *are not* mobilized under stream base flow or dry weather conditions.
- The predominant source materials of the observed elevated fecal coliform concentrations *are increasingly* mobilized to receiving waters as storm water runoff volumes or stream flows increase.

These conclusions suggest that non-storm water related sources of fecal coliform (those sources whose mobilization is not directly or indirectly affected by storm water runoff) do not significantly contribute to the elevated levels of fecal coliform observed in Anchorage streams. They further suggest that the source materials of the elevated fecal coliform concentrations must be either directly or indirectly mobilized and transported by storm water flows, increased stream flows, or both. Given a connection of elevated fecal coliform concentrations to storm water runoff or stream flood flows, some understanding of storm water washoff processes and conveyance systems and stream channel and flood characteristics will be useful in connecting probable sources to the observed exceedances in the streams.

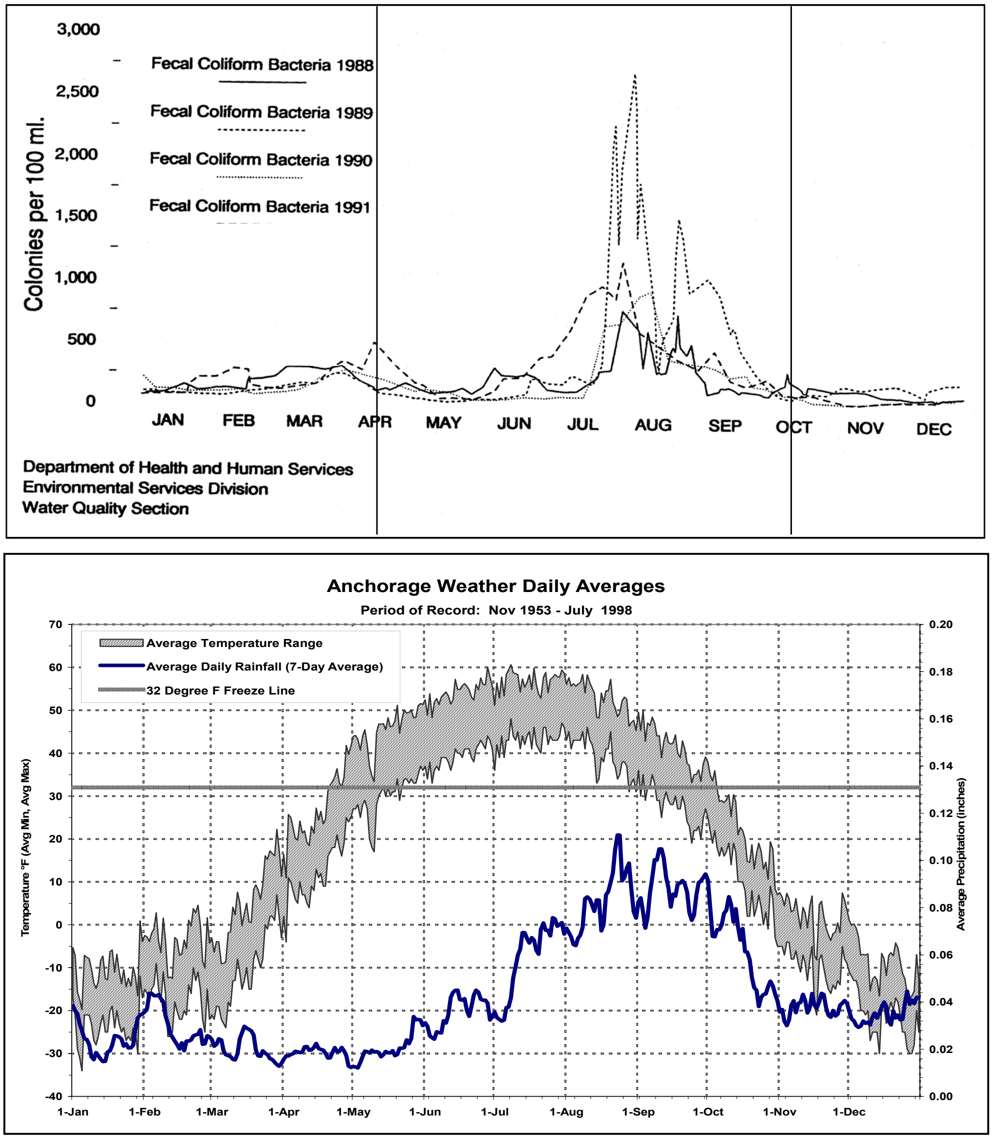

**Figure 1.** Seasonal Climate and Coliform Patterns

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# PART 3 FECAL COLIFORM STORM WATER MODEL FOR ANCHORAGE

Elevated fecal coliform concentrations occur in direct relationship to rainfall, and imply exposure, or release, and mobilization of fecal coliform source materials with precipitation. A similar correlation to peak stream flows suggests that elevated fecal coliform concentrations are also related to flood flow storage and erosion processes in the riparian zone or within the streams themselves. Understanding these processes and the watershed characteristics that influence them, therefore, provides important insight to the most probable sources of elevated fecal coliform in Anchorage streams.

## 3.1 CLIMATE FACTORS

Unusual climatic conditions at Anchorage are particularly critical in interpreting impacts to local receiving waters from storm water runoff. The unique climatic patterns at Anchorage are the result of its northern latitude, coastal location along the North Pacific polar jet stream, and orographic effects from surrounding mountains.

Seasonal precipitation and storm water runoff patterns at Anchorage are driven by the community's northern latitude and transitional maritime location within Pacific coastal mountains. At about 60° north latitude, Anchorage experiences winter days with low solar insolation and temperatures that remain stubbornly below freezing. The area's daily average *maximum* temperature does not exceed 32 degrees Fahrenheit (°F) throughout the winter. Of course, this is true of many mid-west locations as well. However, in Anchorage, January solar insolation (the radiant energy from the sun striking a horizontal surface) is almost an order of magnitude (10 times) *less* than that of cities in northern tier states. Where the sun's heat will cause significant melting along streets and other surfaces at more southerly latitudes, solar radiant energy in Anchorage is too diffuse to cause melt. As a result, significant mid-winter thaw events are rare in Anchorage, and winter-long accumulations of snow and ice (and associated pollutants) are typically released in a single, relatively prolonged, spring melt event.

However, the timing of snowmelt differs for different surfaces (Figure 3), with snow along arterial streets and commercial parking areas melting first, followed soon thereafter by rural residential streets and urban yards and driveways (MOA, 1992a – Appendix G3). Large snow accumulations (including public and private snow disposal storage piles) and snow covering rural residential landuses and alpine areas are the last to go. During the spring melt, infiltration of snowmelt runoff is restricted by frozen ground conditions predominant during the runoff event, increasing the potential for runoff to occur. However, spring melt occurs over a prolonged period (from 15 to 60 days, depending upon the surface) and evaporation and sublimation usually significantly reduce total runoff volumes so that runoff intensity is typically quite low.

With the end of spring melt, storm water runoff patterns at Anchorage begin to closely reflect the effects of the seasonal position of the North Pacific polar jet stream and the character of individual storm events generated along this storm track (USDOC, 1963). At Anchorage, summer and fall rainfall events are the result of stratiform precipitation mechanisms driven by the Pacific sub-tropical, high-pressure belt and associated low-

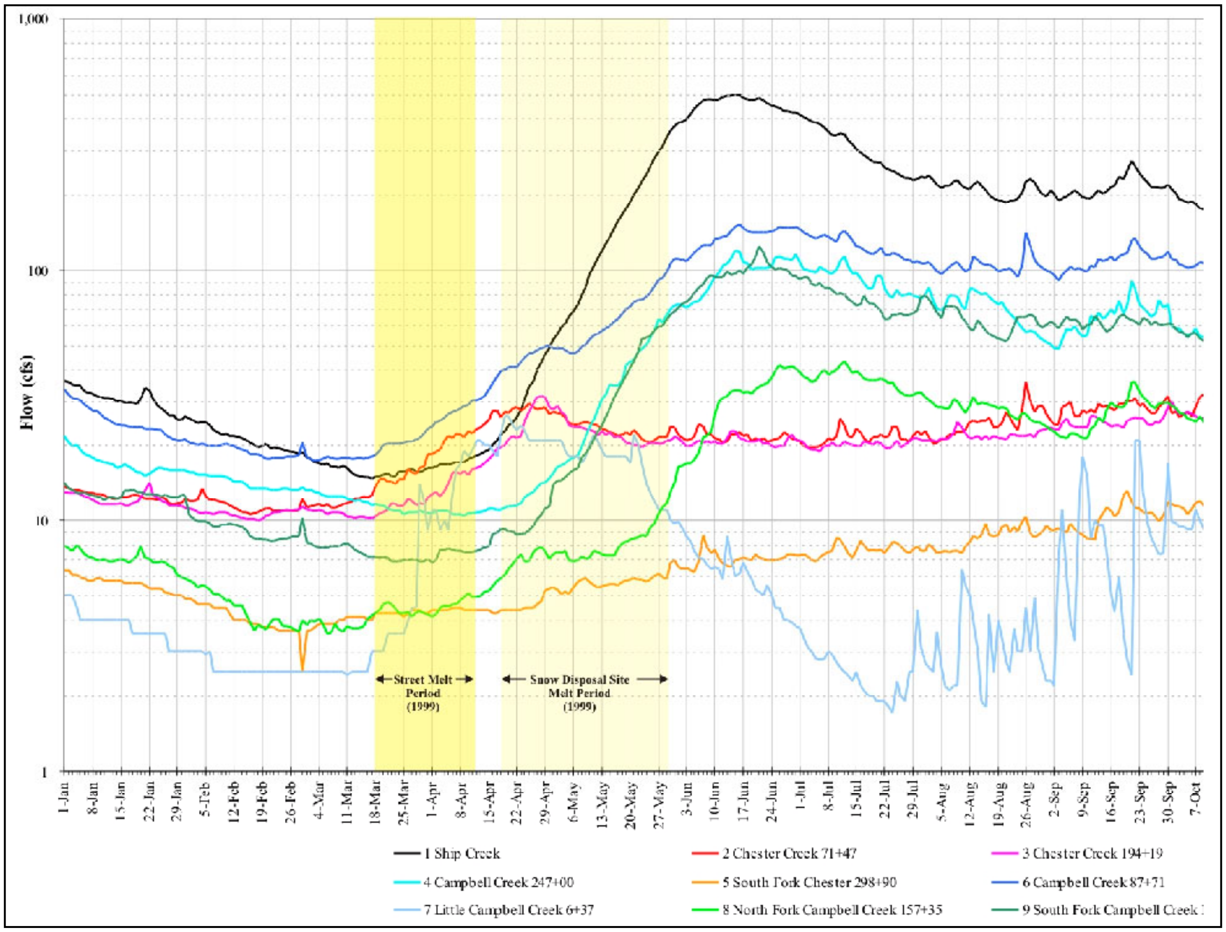


**Figure 3.** Snowmelt Timing from Different Surfaces Versus Average Discharges Using Existing USGS Data.

pressure systems generated along the jet stream. As a result, seasonal rainfall patterns are pronounced. In spring and early summer, with the polar jet stream still in its more southerly track, rainfall events are infrequent and total monthly rainfall is low. As the jet stream moves to its northerly position through the summer and early fall, the number of storm events and monthly precipitation amounts increase. As a result, Anchorage has a pronounced 'dry' season in the spring and early summer and a 'rainy' season that generally lasts from mid-July to freeze-up in mid-October.

However, the late summer Anchorage 'monsoon' season reflects less an increase in total rainfall amounts than it does simply a long parade of gray, drizzly days resulting from the stratiform storm events generated by the approaching polar jet stream. With weather produced by this global storm track, each Anchorage storm event is prolonged but marked by low intensities and small total rainfall volumes. Municipal SYNOP analysis of National Weather Service precipitation data indicate that an Anchorage rainfall event likely to produce runoff is typically 40 hours in length (WMP, 1999b).

In the Anchorage Bowl, these rainfall-producing events have average total volumes of less than 0.4 inches, a significant difference from the high-intensity, high-volume convection-driven events that are common to the Midwest and Eastern Seaboard of the United States.

Rainfall from Anchorage events is also typically distributed relatively evenly over the entire duration of the storm. Thus, each meteorological storm event at Anchorage is usually characterized by long periods of drizzle punctuated by random brief periods of slightly more intense rainfall as a result of 'rain bands' typical of extratropical cyclonic action (Maidment, 1993, p 3.11). This storm pattern is somewhat modified along the mountain fronts surrounding Anchorage, most notably along Turnagain Arm, where volumes are increased due to the orographic lifting generated as the cyclonic fronts push against and across the Chugach Mountains. However, in all cases, rainfall precipitation events at Anchorage are prolonged with no predictable pattern in intensity or volume within a single storm event, and with overall volumes and intensities typically quite low. Most importantly for pollutant mobilization, the low precipitation volumes and prolonged storm durations have a significant effect on storm water runoff through increased potential for losses to detention, infiltration, and evaporation.

At both the seasonal and event scale, these patterns in climate and precipitation have important implications for the occurrence and character of storm water runoff at Anchorage, including:

- Surface runoff does not usually occur during the winter season when temperatures remain continuously below zero degrees Celsius. Streams are at base flow, dependent nearly entirely upon shallow ground water discharges either from natural seepage and springs or from ground water discharging through storm drain pipes or subdrainage systems.
- At the end of winter, spring snowmelt results in an important seasonal runoff event. Runoff from spring snowmelt is prolonged and occurs sequentially across different surface types and at different elevations. Prolonged and sequential melt results in increased opportunities for abstraction to sublimation, evaporation, and detention, and ultimately reduces total runoff volume and daily flow rates. This, in turn, generally results in a low-energy runoff environment during snowmelt, reducing the degree of mobilization of surface fecal matter and associated pathogens.
- Similar to the winter season, lower precipitation amounts during the early summer are reflected in the occurrence of little or no runoff, although many stream flows rise as a result of the beginning contribution of alpine snowmelt and shallow ground water recharge from regional snowmelt. This early-summer dry season also results in a deficit in surface soil moisture, so that soil pore space and infiltration capacity are at maximums by the end of this period.
- The onset of an increasing frequency in mid-summer and fall rains raises the potential for runoff events. Higher runoff volumes are more likely as this season progresses because precipitation remains relatively high as soils become wetter and detention and infiltration capacities decrease. However, even during this 'wet' season the nature of storm events at Anchorage (low volume, low intensity, long duration) result in a high sensitivity of runoff volume to runoff surface character. That is, because precipitation events are prolonged and have low intensity and volume, relatively small changes in surface detention and infiltration capacity can significantly influence the total runoff volume resulting from any single storm.

## 3.2 LANDCOVER FACTORS

Geography and geology always play prominent roles in determining how precipitation will convert to storm water runoff and, thus, the nature and extent to which pollutants, including fecal matter and pathogens, are mobilized. Similarly, to the degree that these factors are also correlated to the presence of specific sources of fecal material, their characterization will be vital in understanding mobilization of fecal coliform pollutants to Anchorage streams. Landcover mapping summarizes the geologic and hydrologic characteristics of land surfaces as modified by human beings. Thus mapping the character and distribution of landcover is a key element in evaluating the potential for the generation of both pollutants and storm water runoff.

Within the MOA, predominant landcover types have a distinctive spatial distribution. In highly urbanized areas, landcover is dominated by impervious surfaces (streets, parking, roofs, and driveways) and landscaped lawns. Impervious surfaces are densest across the lowlands of the Anchorage Bowl (particularly along the Seward Highway transportation corridor – Figure 4), and in the vicinity of the Eagle River business district.

In these densely urbanized areas, impervious surfaces commonly account for a third to more than half of the total watershed area. Landscaped surfaces, particularly lawns, often account for much of the remaining land area. Lawn surfaces are particularly abundant in the lower parts of Campbell, Little Campbell, Furrow, Carol, Meadow, and Eagle Loop Creek watersheds, and throughout most of the Chester, Fish, and Hood Creek watersheds where individual residential lot sizes are small. Outside of these densely urbanized areas, major commercial and transportation corridors occupy much smaller fractions of the total land area and residential lot sizes are typically much larger. As a result, the fraction of watershed area in impervious surfaces and lawns is substantially less (typically less than 5 to 15 percent for both landcover types combined) (WMP, 2002b, Appendix P3).

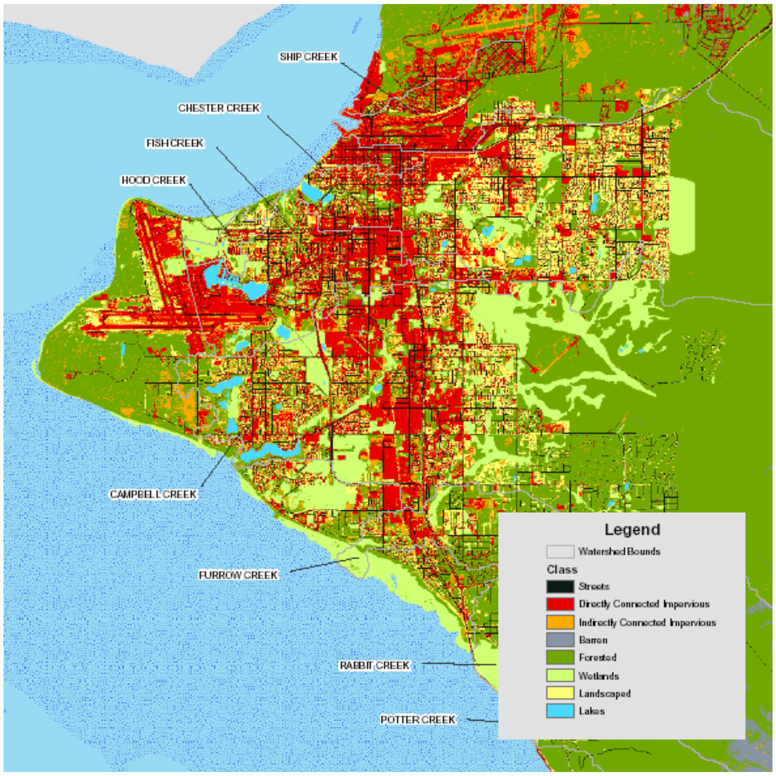


**Figure 4.** Storm Water Runoff Landcover

Both impervious surfaces and lawns in highly urbanized areas contribute significantly to storm water runoff. The extensive impervious surfaces in the densely urbanized areas are very responsive to even the small rainfall events typical of Anchorage, and rapidly generate and release the largest storm water runoff volumes of any surface types. However, impervious surfaces are not thought to generate significant fecal coliform loads of themselves (WMP, 2001c, Appendix G3).

Urban lawns are much less responsive to precipitation than impervious surfaces, but nevertheless, dramatically increase storm water runoff relative to pre-development conditions. Construction of compacted ground and uniformly sloped surfaces to build a lawn, and maintenance of a tight-rooted grass cover is believed to decrease infiltration and detention capacity of the original ground cover by at least an order of magnitude (WMP, 2001c, Appendix G3). As a result, lawns provide optimum conditions for storm water runoff, particularly during the latter part of the 'wet' season when the compacted soils achieve high antecedent moisture conditions.

Significantly, and unlike streets, lawns *are* a source of abundant fecal material (from domestic pets) that can be mobilized with the storm water runoff generated by the lawn surface. In highly urbanized areas, lawns are also often graded to drain directly onto adjacent streets. This typically increases the potential for successful mobilization of fecal pollutants into streams as a result of the increased carrying capacity of the street drainage systems. Storm water runoff from lawn surfaces usually occurs as a low-energy sheet flow capable of mobilizing only dissolved substances and very fine particulates. Simple detention and filtration systems are adequate to remove much of even the fine particulate pollutants from these small, low-energy flows. Conversely, street drainage (particularly curb and gutter systems served by storm drain pipes) is designed to promote much more energetic channelized flow in order to remove water rapidly from trafficking surfaces. Fine particulates, including those entering from adjacent lawn sheet flow runoff, are easily and preferentially mobilized by the relatively high-energy flow along street curb and gutter systems and are generally difficult to treat once they have entered piped storm drain systems (WMP, 1999c, Appendix G5).

Lawn surfaces in the less densely developed residential areas will generate the same amount of storm water runoff and mobilized fecal material per unit area as those in densely developed areas. However, lawn surfaces in the more rural areas comprise a smaller fraction of the total local drainage area and often these lawn surfaces do not drain directly to street curb and gutter drainage systems. Dog lots, stables, and other concentrated animal husbandry operations more common to outlying residential areas may be important local exceptions to this generalization, but are also easily targeted for application of on-site controls.

## 3.3 RIPARIAN ZONE FACTORS

There is a growing awareness nationwide that the character of riparian zones significantly influences the degree to which urban activities impact receiving waters. Riparian zones can be managed to provide a variety of economically and socially vital services to urban communities but, improperly managed or maintained, can be a considerable source of fecal contaminants (and other problems). Riparian areas are natural corridors for wild animals. They are attractive sites for trails and parks and the humans that build them (along with their pets). All of these riparian zone visitors contribute directly to fecal contaminant loading in Anchorage streams and, locally, contaminant contributions from riparian areas can quite easily exceed those from other landuses.

Within riparian zones, domestic animals (and less frequently, humans) directly contribute fecal material to municipal receiving waters. In Anchorage, streams are preferential sites for urban trails and parks. Trails provide access usually for recreation and, less frequently and very locally, for occupancy within the undeveloped riparian zones by the homeless. In fact, the few reports of human wastes observed in riparian zones have typically been associated with local summer occupancy of these undeveloped areas by vagrants. However, the vagrants' camps are usually well set back from any receiving waters (both for reasons of practicality as well as of concealment) and, as a result, the wastes associated with them are likely to have only limited mobility in storm water runoff.

More typically, streamside trails provide casual recreational use to local residents who may frequently be accompanied by their pets, particularly dogs. The visible results of these trail excursions has made pet wastes on trails a primary target for MOA control over the years. However, where recreational trails are separated from the stream channels by naturally vegetated buffers, the potential for storm water mobilization of fecal material directly into the stream from along these routes can be greatly reduced (Bohn and Buckhouse, 1985, p 96; Kunkle, 1970, p 129). A more significant potential for washoff of pet and other animal wastes occurs at landscaped riparian zone parks, where frequent compacted lawn surfaces often encroach directly onto the banks of receiving waters.

Locally, wild animals may commonly contribute the largest fraction of the total fecal material that is deposited directly to MOA urban riparian zones and streams. Wild animal usage of urban riparian areas is, in part, a natural effect of the peninsular geography of the MOA. Ironically, however, fecal contaminant impacts from these occupants may be influenced by how urban riparian areas have been developed as well. Anchorage is an unusual metropolitan area in that it is drained by many small streams and closely bordered by wildlands. Most of the streams crossing Anchorage urban areas have headwaters within wild, undeveloped mountainous uplands, and flow through urbanized areas to mouths that are located along equally wild, undeveloped tidal marshes and coastal wetlands. Wild animals have always used the cover and food of the riparian zones along these streams as corridors for local migrations between winter and summer ranges, and as nesting grounds. Although development has resulted in loss of a substantial fraction of riparian land along the more urbanized intervening reaches, substantial undeveloped fractions still remain. As the streams and their riparian zones continue to serve as corridors for local seasonal migration and refuge, the series of partially connected riparian nodes along the urban reaches also continue to act as part of these animals' natural range. Now, as a result of the riparian losses due to urbanization, wild animal impacts on streams may, in fact, have increased as populations are constrained by the constantly narrowing riparian corridors.

## 3.4 STORM WATER DRAINAGE FACTORS

Although landcover is the prime determinant in the generation of storm water runoff and fecal contaminants, storm water drainage systems play the principle role in determining the degree to which the fecal contaminants are conserved and transported to a receiving water. Storage and re-suspension processes in these storm water conveyances, as well as in the streams themselves, also play critical roles in the occurrence, timing and magnitude of exceedances of fecal coliform standards.

Storm water runoff within the MOA is generally carried by either piped or open-channel ditched systems. Distribution of these two basic types of storm water drainage systems is spatially well defined across the MOA (Figure 5). Most piped storm drainage systems (and associated curb and gutter street drainage) are located in the Anchorage Bowl and general vicinity of the Eagle River business center. Outside these areas, storm drainage is primarily carried by open ditch systems.

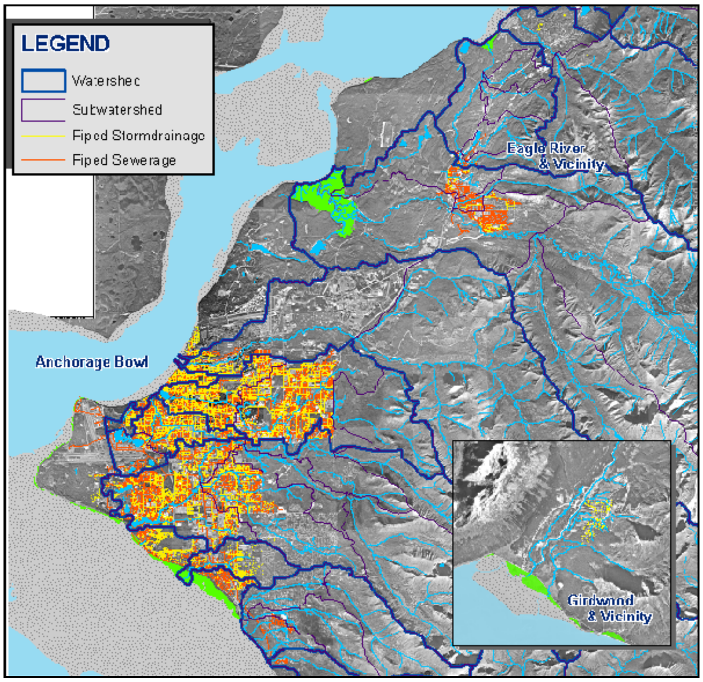


**Figure 5.** Piped Systems in the MOA

Interestingly, type of sanitary wastewater facility (piped sanitary sewer vs. on-site systems) has a spatial distribution similar to that of storm water systems. Areas having piped storm drainage are typically also served by piped sanitary sewer systems, and those with ditched drainage systems are served by on-site drainfield systems. Despite the spatial match, however, the MOA has never permitted the same pipe systems to be used to carry combined sanitary wastewater and storm water. No connections are permitted between piped sanitary sewer systems and storm water drainage systems. Similarly, the design and location of on-site drainfields are tightly regulated to ensure adequate pathogen removal and to prevent direct surface discharge of drainfield wastewater to receiving waters or open channels. Nevertheless, it has been too easy for investigators in the past to conclude that patterns in fecal coliform concentrations in area streams are driven by a particular sewer disposal practice, without controlling first for the very obvious and more probable determining factors of storm water drainage system type.

In fact, national research has consistently shown that piped and ditched systems perform in significantly different ways in conveying storm water (O'Reilly and Novotny, 2000). As described earlier, piped curb and gutter street drainage systems increase the opportunity for transport of fecal coliform contaminants generated on adjacent landuses. Conversely, ditched drainage systems (and particularly vegetated swale systems) reduce pollutant transport as a result of reduced runoff (through detention and infiltration) and increased pollutant treatment (through filtration).

A key distinction in performance of the two drainage systems types at Anchorage is in the reduction of total rainfall runoff volume as a result of infiltration along ditched systems. Water quality sampling completed during preparation of the MOA's initial application for its NPDES permit to discharge storm water illustrates this. A series of late summer attempts at storm runoff sampling along an Anchorage Hillside ditch system was frustrated until mid-September, as a result of loss of all runoff to ditch infiltration. Despite the occurrence of a number of rainfall events with total volumes greater than those for basins having piped systems (and for which sampling was successful), no runoff occurred in the ditched basin until ditch soils became saturated from repeated runoff. When storm runoff finally was produced at the Hillside site, runoff was about one-quarter of that produced at the piped sites, despite the fact that the Hillside precipitation volume was twice that of the lower stations (MOA, 1992a, Part 2). This type of response is relatively common for ditched systems serving rural Anchorage land developments, except on steeper hillsides in areas of shallow bedrock or low-permeability surface soils. In contrast, piped systems typically rapidly produce runoff from connected impervious surfaces and are significantly responsive to runoff produced from adjacent lawn surfaces, particularly as Anchorage's rainy season progresses.

Although, as a result of reduced runoff response, ditched systems are expected to provide greater opportunity for treatment of fecal contaminants, both piped and ditch systems may change the timing of contaminant release through temporary storage and later re-suspension and release of sediments. Because fecal coliform adsorbs readily to particulates, coliform may be stored temporarily as the result of particulate matter settling at low-velocity points in conveyance systems (WMP, 2002c, Appendix P1). This type of storage is possible in either piped or ditched systems and can lead to a reduction in fecal coliform transported to receiving waters during lower flows (as a result of in-system settlement and storage), or to increases during higher flows (as a result of scour and entrainment of previously settled particulates and their adsorbed coliform load). However, relative to pipe systems, the potential in ditch systems for vegetative filtration and reduction in total storm water runoff volumes maximizes potential for settlement and storage and minimizes potential for sediment re-suspension.

## 3.5 STREAM CHANNEL FACTORS

Sedimentation, storage, and re-suspension processes within stream channels similar to that in storm drainage systems can also significantly affect fecal coliform concentrations during stream flood flows (Auer and Niehaus, 1993; Bohn and Buckhouse, 1985). Fecal coliform bacteria from land and riparian zone sources adsorb to street and stream sediments, preferentially to those with higher organic contents and particles sizes ranging from about 1 to 100 micrometers (µm) in diameter (Pettibone and Irvine, 1996; Wilkinson et. al., 1995; and Kobriger and Geinopolos, 1984). These particles are periodically transported, settled, and then re-entrained (along with their coliform load) in direct response to the stream flood flow regime and local stream channel characteristics. The mechanism works in the following general manner. During low flow events, fine sediments and their adsorbed coliform load settle and collect on the stream bottom. When stream flows increase in response to storm water runoff events, the fine bottom sediments along with the coliform are re-suspended, resulting in increased fecal coliform concentration in the water column.

Several controlled river discharge experiments have shown that fecal coliform stored in stream bottom sediments may be scoured and entrained relatively abruptly at specific threshold levels in increasing flood flows (Kunkle, 1970; Wilkinson, et. al., 1995, McDonald et. al., 1982). As a result, increases in water column concentrations derived from bottom sediment entrainment are manifested as sort of 'first flush' pulses. The initial entrainment pulse increases the concentration of fecal coliform in the local water column, which is then rapidly transported downstream as a concentration front. After the initial entrainment event, local concentrations in fecal coliform fall off until stream flows again increase above some threshold level sufficient to entrain the next pulse. Given repeated scour events, the total fecal coliform load initially stored within the bottom sediments can be completely depleted, so any further sediment entrainment will not contribute to increases in water column fecal coliform concentrations. Finally, a general decrease in stream discharge energy as flood flows recede may result in re-settlement of entrained sediment (transported from upstream scour sites) back to the stream bottom.

A range of evidence suggests that stream bottom sediment re-suspension may be a very significant mechanism driving the timing and magnitude of the elevated fecal coliform concentrations observed in Anchorage stream water. The presence and importance of seasonal and storm event-driven sedimentation and re-suspension of bottom sediments in Anchorage's streams was first recognized in early studies performed as part of the *Metropolitan Anchorage Urban Study* (USACE, 1979a, b). A more recent thesis investigation (Kidd, 1989), showed that Anchorage stream bottom sediments are host to fecal coliform populations in concentrations significantly higher than that of the overlying water column. In the Kidd (1989) study, samples were collected through a single winter from sites across the urbanized Anchorage Bowl. Initial late-fall sample concentrations, ranging from about $2x10^3$ to $6x10^4$ colonies per 100 ml of dry sediment, declined by about an order of magnitude across a continuing series of samples collected through mid-winter. Simultaneous water column, 20-day mean concentrations ranged from $1x10^0$ to $2x10^2$ col/100 ml.

In Kidd's study, sampling was performed during a normal period of baseflow for Anchorage. Thus, reported declines in bottom sediment concentrations over the sampling period were likely the result of in situ decay, and not a result of bottom sediment scour and displacement. Nevertheless, the reported late-fall sediment concentrations may reasonably be interpreted as reflecting typical end products of suspension and re-settlement of stream bottom sediments following late-summer and early fall rainfall runoff flooding. It is also notable that bottom sediment coliform concentrations reported by Kidd are about one order of magnitude higher than mid-summer flood flow water column concentrations typical of urban Anchorage streams. This difference suggests a significant role for sedimentation and bottom sediment re-suspension in the occurrence of elevated fecal coliform in Anchorage streams during flood events.

However, a bottom sediments-based model for elevated fecal coliform concentrations in Anchorage streams must also explain an apparently contradictory seasonal pattern for these contaminants in the water column. Substantial data shows that stream fecal coliform concentrations tend to drop off substantially *before* the local fall rainy season ends (see discussion in Part 3). This seems contrary to observations showing that substantial fecal coliform from storm water runoff continues to enter streams throughout the late Anchorage rainy season (WMP, 2002a; MOA, 1992a; USACE, 1979a b). In fact, the early drop in stream fecal coliform concentrations suggests more that storm water runoff is *not* the sole mechanism in generating elevated stream fecal coliform concentrations. If the primary mechanism driving the elevated fecal coliform concentrations observed in Anchorage streams was simply due to input from storm water runoff, one would expect stream concentrations to continue at elevated levels throughout the rainy season, and perhaps even increase as contributions begin from late season ditch flows. In fact, the opposite happens and stream fecal coliform concentrations tend to fall off in late summer, well before the end of the rainy season.

On the other hand, if a seasonal sequence of bottom sediment storage and entrainment is a predominant mechanism in development of elevated fecal coliform concentrations in streams, seasonal *depletion* of stream bottom-stored fecal coliform as a result of the continual barrage of rainy season flood events can explain the early drop off in water column fecal coliform concentrations. In explanation of this type of phenomenon, McDonald, et al. (1982) report that flood flows can deplete the store of fecal coliform in stream bottom sediment. Also, further flood flows from upstream reaches that have been swept 'clean' of bottom-stored coliform may actually act to dilute downstream contributions from other land-based sources of fecal coliform contaminants. Such a seasonal sediment buildup and depletion process can provide a model that adequately explains the apparently contradictory early seasonal drop in stream fecal coliform concentrations observed in Anchorage.

## 3.6 ANCHORAGE FECAL COLIFORM STORM WATER MODEL

An acceptable model of fecal coliform in Anchorage streams must reflect the observed pollutant contributions in storm water runoff from various landcovers and, at the same time, reasonably explain seasonal variations in stream fecal coliform concentrations seemingly contradictory to those observed in storm water runoff. The model proposed here meets this test. It recognizes urban residential landuses and riparian areas as primary fecal coliform pollutant generators, and fine sediment as an important carrier of these pollutants. The model reflects an annual cycle, including:

- Winter land-based pollutant accumulation.
- Spring and early-summer land-based pollutant mobilization and transport in low-volume snowmelt and rainfall runoff events.
- Spring and early-summer in-stream sedimentation associated with land-based storm water pollutant inputs.
- Mid- to late-summer in-stream scouring and re-suspension of stream bottom sediments associated with increasing magnitude of seasonal flood flows, leading ultimately to depletion or near-depletion of the stored stream bottom pollutant load.
- Mid-summer through fall land-based pollutant mobilization in storm water and continuing input to streams.
- Late-fall 'recharge' of in-stream contaminated bottom sediments as a result of settlement or re-settlement of storm water pollutant inputs with waning seasonal stream flows.

- Winter storage and partial preservation (as a result of cool, low-light conditions) of bacterial pollutants adsorbed to stream bottom sediments.

This cycle entails an initial land-based winter accumulation of (almost entirely non-human) fecal material within the watershed and the riparian zone. These materials are mobilized in low-volume snowmelt runoff and early summer rainfall runoff events. In the process of storm water mobilization, fecal bacteria and other pathogens preferentially adsorb to and are transported with fine particulates. When spring and early summer runoff enters stream channels, settlement of the particulate matter is favored (at least locally) over scour and transport as a result of the low flows predominant in Anchorage streams at this time of year. This spring and early summer sedimentation helps to annually 'prime the pump' for later water quality exceedances by adding to the store of fecal coliform in the bottom sediments amassed in the late fall of the previous year.

Later in mid-summer, as the rainy season begins in earnest and storm-driven flood flows increase significantly in magnitude, the bottom sediments are scoured. At the beginning of the rainy season, with the stored mass of fecal coliform at a maximum, flood scour results in release of large 'pulses' in fecal coliform to the stream water column. Mid-summer storms generate runoff that carries land-based fecal contaminants into the stream flow as well, but the re-suspended bottom sediments are the primary reason for the large, mid-summer peaks in fecal coliform concentrations in Anchorage's streams.

This conclusion is supported by several observations. First, initial seasonal peaks in concentrations occur early with the onset of the rainy season and in close association with the beginning of increased stream flood flows and increased bottom sediment scour. Second, these early seasonal peaks drop significantly in mid-rainy season even as contributions from land-based storm water runoff still remain relatively high. This suggests that a significant mechanism, or mechanisms, is at work to *lower* stream fecal coliform concentrations despite land-based contributions that should tend to *raise* them. Brabets and Wittenberg (1983) suggested that dilution from undeveloped upstream reaches can account in part for the seasonal changes in fecal coliform patterns observed in Anchorage streams. Although dilution is likely a factor, the same seasonal pattern is seen even in those streams that have only small, undeveloped alpine headwaters (and thus little contribution of 'clean' diluting storm water or snow melt). Thus, although a complex of factors participates, a mechanism of depletion of stored fecal coliform in bottom sediments appears to be required to fully explain this seemingly contradictory situation.

The early seasonal peak and subsequent drop in fecal coliform concentrations in stream water is likely the result of depletion of the fecal coliform store in the bottom sediments as stream flood flows seasonally increase in magnitude and frequency, and scour predominates. Limited data suggests that, at mid-summer, continuing land-based pollutant contributions in storm water may also drop off from an early peak (WMP, 2002b). This may occur as a result of reduction in the total available fecal matter on land surfaces, (i.e., pollutant washoff operates faster than pollutant buildup). However, absolute concentrations in urban runoff still remain relatively high throughout the entire rainy season, so that any seasonal decline in runoff concentrations does not seem able to fully explain the drop in in-stream concentrations.

In any event, depletion occurs despite pollutant contributions from land-based storm water because a substantial fraction of *both* the scoured and storm water-transported fine particulates are not re-deposited. Rather, the bulk of the pollutants generated from both scouring and storm water-transport are carried completely out of Anchorage's small stream networks and into Cook Inlet, as a result of energetic rainy season flood flows. Simultaneously, ground water and alpine snowmelt contributions to streamflow are increasing. Depletion of the contaminants in the bottom sediments and addition of relatively contaminant-free ground water and snowmelt dilutes the effects of continuing fecal contaminant contributions from urban storm water runoff and riparian zone source areas. Because the timing of depletion of bottom pollutant stores apparently occurs relatively early in the season, the overall result is a decrease in water column concentrations in mid-season—despite continuing high storm water runoff contributions.

Important variations are likely to occur locally as a result of differences in the extent and pattern of alpine snowmelt and ground water recharge and its influence on a specific stream's flow regime, upon land development and drainage systems within a particular watershed, and upon the characteristics of the stream channels themselves. Nevertheless, a general pattern of falling fecal coliform concentrations in late summer is apparent at all Anchorage urban streams.

Finally, the seasonal cycle in fecal coliform loading to the streams closes as freeze-up arrives and storm water runoff ceases. As streams return to lower-energy base flow conditions, sediment and adsorbed bacteria still being transported through the stream system have an opportunity to settle and, to a limited extent, 'reload' the stream bottom. After freeze-up, however, little additional fecal coliform is added to the typical Anchorage stream over the winter, and coliform concentrations in stream bottom sediments generally decrease as a result of die-off. Nevertheless, a significant fraction of the coliform population is likely to survive due to cool temperatures and low light conditions. Survival rates may be further enhanced, depending upon stream bottom sediment particle sizes and organic content. In any event, the remnant stored in stream bottom sediments will add to the pollutants transported in spring snowmelt at the beginning of the next annual cycle.

With this model in mind, several factors may particularly promote a pattern of stream bottom sediment storage and release in Anchorage, aggravating seasonal elevations in in-stream fecal coliform concentrations. These include: piped storm drainage; stream channelization, ditching, and armoring; winter grit application (as a traction-enhancing treatment for icy roads); and channel obstructions.

Increased direct hydraulic connection of urban storm water runoff to streams results in the type of rapid and large peaks in stream flood flow that national research has suggested specifically trigger bottom sediment re-suspension. These types of stream flood flow responses are typical of highly urbanized stream reaches in Anchorage, and are particularly notable along most of the lower reaches of Chester and Fish Creek (Figure 6).

Stream straightening and ditching rapidly transmit these peak flood flows (minimizing attenuation in flow energy), and promote bank erosion. Unfortunately, channelization of streams at Anchorage in support of urban land development has been a common practice

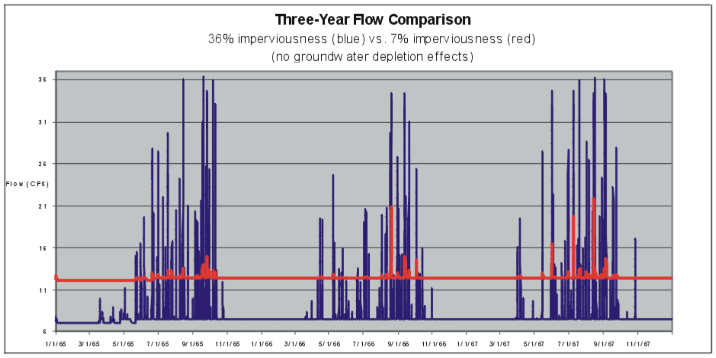


**Figure 6.** Flow Comparisons for Chester Creek

and continues unabated today, particularly along lower-order tributary streams in all hillside areas of the MOA.

Grit applied to Anchorage roads and parking surfaces to enhance winter traction contributes an additional fine-grain sediment load to MOA streams. Neither the applied grit nor eroded bank sediments are thought to contribute significant fecal material to stream flow, but the fine-grain sediment does provide optimum adsorption and protective sites for bacteria and pathogens.

Finally, channel obstructions combined with channel straightening may significantly increase sedimentation sites along Anchorage urbanized streams (Figure 7). Stream channelization often results in widened, shallow channels, and is a typical result of ditched streams in Anchorage (WMP, 2000, Appendix L). Stream crossings placed along these widened channels frequently result in shallow, upgradient impoundments, particularly as a result of flow obstruction at overly-narrow, armored crossings. These long (some measured at over 300 feet in length), shallow impoundments have prolonged detention times and small settlement depths compared to natural pools. Consequently, they function as excellent

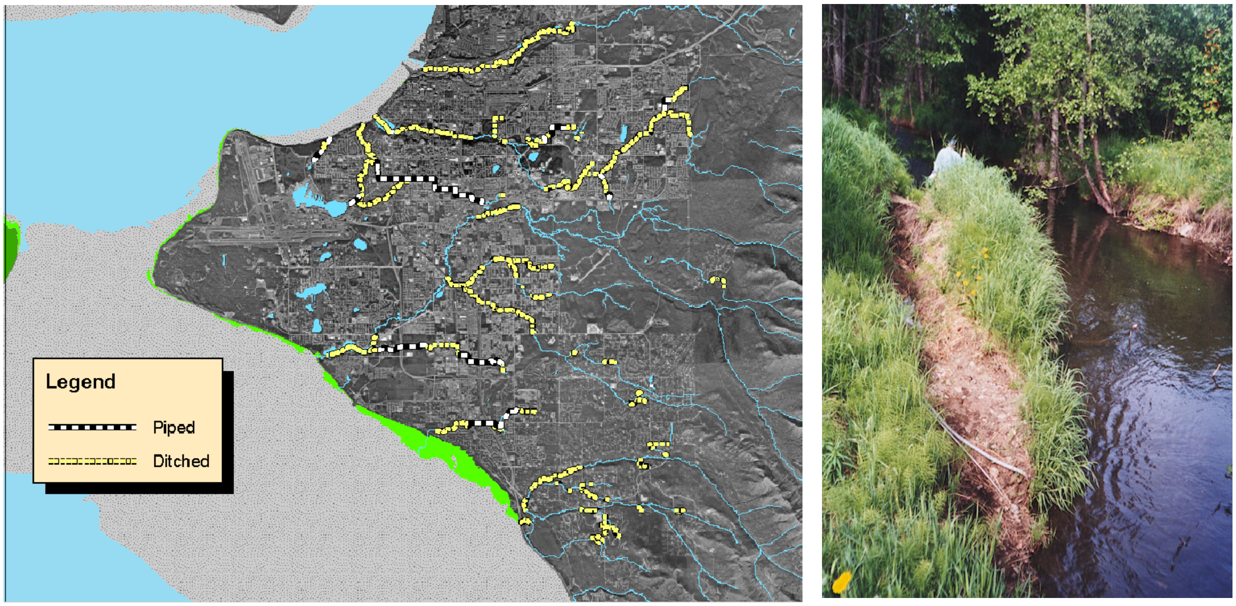
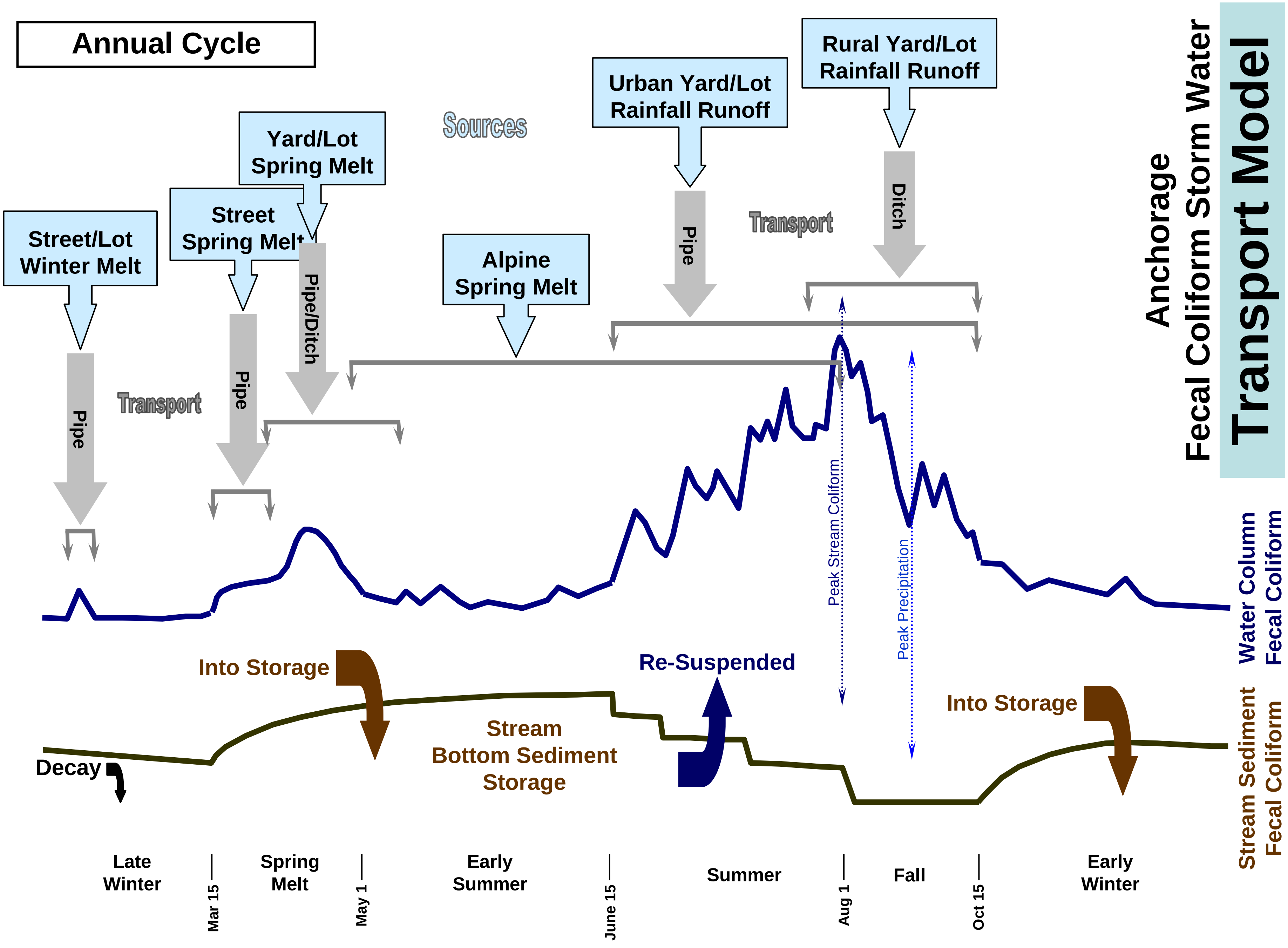


**Figure 7.** Stream Channelization in Anchorage

sedimentation sites during base flow and smaller flood flows. However, for larger flood events, their shallow depths and linear orientation make them exceptionally subject to scour. As a result, these long, shallow impoundments may be particularly important in sustaining elevated fecal coliform concentrations through the process of settlement, scour, and re-suspension of stream bottom sediments.



# Anchorage Fecal Coliform Storm Water Transport Model

# PART 4 FECAL COLIFORM SOURCES AND DISTRIBUTION IN ANCHORAGE

In over 30 years of investigations, many different sources have been explored as possible origins of the fecal coliform contamination observed in Anchorage streams. In many of these investigations, source assumptions were based on patterns observed for similar problems occurring in the continental United States. Only very rarely did early Anchorage investigations attempt to test these postulated sources in context with a full range of *local* storm water drainage systems and processes, including effects of winter accumulation of pollutants and ditch responses to precipitation (USACE, 1979a, b; MOA, 1992a; WMP, 2002a).

Unfortunately, even when system elements were considered, investigators typically did not control for these factors in their experiments sufficient to allow results to be dependably applied beyond study areas. Some early investigations did recognize the importance of influences from local geology and shallow ground water on fecal coliform mobility (DHHS, 1986a; 1990a). However, soils anisotropy reflecting late glacial geomorphology and spatial variability in climate and systems performance across the MOA was not accounted for. As a result, investigations' often yielded highly variable data, making it difficult to reliably interpret the information at a large scale (DHHS, 2000). Finally, some early investigations' disregard for, or limited understanding of, a plethora of complexly-interrelated watershed factors, and a too-frequent focus on identification of 'hot spots' rather than description of overall systems interactions and performance has led over the years to quite contradictory reports of probable fecal coliform sources (DHHS, 1987c; DGGS, 1987). As a result, data could be found to make a case for any suggested source as the cause of the elevated fecal coliform observed in Anchorage streams—and there seemed to be no shortage of advocates to do just that.

In the last 10 years, the MOA has taken a much more systematic approach to understanding the sources of problems and impacts from urban storm water. To support specific storm water management applications and in context with whole drainage and receiving water systems, MOA investigators have collected data to describe processes and performance of local watershed and storm water control elements (WMP, 2000, p 73). Data has been collected specifically to help provide insight into the critical interrelation of factors of climate, geology, hydrology, landcover, landuse, and drainage system and receiving water character. This wholistic investigative approach, in conjunction with historic MOA data and national research findings, has allowed development of a preliminary model (described in brief in the preceding section) for storm water pollutant generation and transport (including fecal coliform) that is generally consistent with currently available data. In context with the model described in the previous section, various potential fecal coliform sources have been assessed as representing 'minor' or 'major' contributions to stream fecal coliform concentrations.

Almost every possible source of fecal coliform contaminants either has or does contribute to the fecal coliform loading measured in Anchorage streams—to some degree. The degree to which each contributes, however, is not a trivial issue. The risk to human health represented by the presence of fecal coliform depends, to some extent, on the source of the fecal coliform, the magnitude and the periodicity of the contribution of the originating fecal contaminants, and (in this particular case) the contaminants' mobility in storm water. Although this document is not intended to assess human risk represented by fecal coliform in Anchorage streams, source, magnitude, periodicity, and mobility information is certainly fundamental to that risk assessment. In this context, the MOA has broadly categorized source types as 'minor' or 'significant' to clearly separate sources in terms of incidence and volume of contribution of fecal material to MOA storm water and streams.

Available data for Anchorage does not allow direct quantitative assignment of fecal contaminants measured in streams to particular sources. However, significant circumstantial data does exist that provides a means to reasonably characterize the frequency and volume of contributions from different sources. Therefore, for purposes of this analysis, *'minor'* fecal coliform contributors are generally defined as those sources for which data suggest some combination of a very low recurrence, a high localization, and a low volume of contaminants, along with a generally low mobility in surface storm water runoff. Conversely, *'significant'* contributors are defined as those sources for which data suggest a regular recurrence, a wide distribution and relatively large volume, along with a significant mobility in surface storm water runoff.

## 4.1 MINOR SOURCE CONTRIBUTORS

Minor fecal coliform contributors are defined as potential fecal contaminant sources, but for which data suggest some combination of a very low recurrence, a high localization, and a low volume of contaminants, along with a generally low mobility in surface storm water runoff. Sources identified as minor contributors include piped sewerage, on-site drainfield systems, street sediments, and coliform incubation and growth in storm pipes.

### *4.1.1 Piped Sewerage Systems*

Piped sewerage systems can be a source of fecal contaminants in streams for a variety of reasons. In the past, using a single pipe to carry both storm water and sewage flows (called combined sewer outfalls or CSOs) was a common practice in the continental United States. In these types of systems, under normal conditions, all flows – including both sewage and storm water, would be transported in the same pipe system to a treatment plant before discharge to receiving waters. However, during large storm water runoff events, when the treatment plants could not handle the increased flows, these systems would bypass excess flows past the treatment plants and discharge untreated effluent directly into streams. In addition to CSOs, sewage discharges can also occur as a result of poorly controlled pipe system construction practices that lead to unintentional connection of sewer pipes to storm water systems (called a 'cross connection'). Sewage discharge can also occur when poor design and maintenance of the sewage pipes results in sewage leaks or overflows to receiving waters.

None of these practices are common in Anchorage, and human sewage from piped sewerage systems is not considered a frequent or widespread source of fecal coliform in local streams:

- Human wastes from piped sewerage systems are not a significant source of fecal coliform in Anchorage streams. The MOA does not currently, and has never in the past, used

CSO systems. Throughout the continental United States, a pervasive source of fecal contaminants in stream waters has resulted from the use of combined piped systems to carry both sewage and storm water runoff. These systems can often result in significant discharges of human sewage to streams during larger storm events. As a result of the national extent of this problem, these combined sewer outfalls have long been a focus of control for many states and the EPA. Unfortunately, a common assumption for agencies is that CSOs do or have existed in every community. However, for the period of most major urban expansion in the Anchorage area (1960s to the present), community sewerage and storm water systems have been designed and inspected under Borough or MOA design criteria that have prohibited any use of CSO-type designs (GAAB, 1974; MOA, 1994; AWWU, 1990, 1994, 1985).

- Anchorage lies on a mountainous peninsula with the fortunate result that municipal piped sewerage is comprised almost entirely of gravity systems. The few pressurized systems (force mains) that do exist in the network are chiefly located outside upland watersheds and near or in intertidal zones. As a result, although leaks from pressurized sewage systems are possible, significant contribution from these sources to Anchorage's fecal coliform problem is unlikely. On the other hand, gravity mainline sewage systems are often routed along stream riparian zones, where ground water is typically very shallow (within a few feet of the ground surface). However, minimum burial depths required by MOA criteria for sewer pipes generally place the pipe invert below the shallow ground water depth. As a result, hydraulic pressure gradients are *from* the ground water system *into* the pipe. That is, problems are invariably related to ground water infiltration *into* sewer pipes rather than exfiltration from the pipes to the ground water (and into nearby streams).
- Although cross connections have been uncovered within the MOA, these have been rare and have been repaired in every case. Very few Anchorage stream sampling investigations have implicated non-storm water point sources in fecal coliform impacts on streams and, in most cases, these sources have typically been unusual and non-pervasive. Analysis performed by the MOA in 1985 and 1986 of 184 suspected fecal coliform sources along Fish, Chester, and Campbell Creeks yielded only two pervasive human point sources—both sewer cross connections that were corrected at the time of the investigation (DHHS, 1987a).
- The periodicity of observed stream fecal coliform exceedances does not support a continuous fecal coliform origin (as would be expected from piped sewer systems) as a primary source of the fecal contamination. Fecal coliform concentrations measured in Anchorage streams have consistently shown a drop of several orders of magnitude between winter and summer flow regimes (MOA, 1992a, Part 1, Figure 4-5; DHHS & ADEC, 1990). A recent U.S. Geological Survey (USGS) study (Frenzel and Couvillion, 2002) suggested only a modest difference in winter versus summer concentrations, but sample set sizes for this study were very small and sampling stations widely distributed across a range of watershed and stream characteristics. The much more robust DHHS dataset and the bulk of all data collected at Anchorage over the years, show a strong summer versus winter drop in fecal coliform concentration—particularly for urban reaches. However, if piped sewer systems were primary contributors, winter concentrations would be expected to remain elevated as the effects of dilution from storm

water runoff, alpine snowmelt, and ground water seasonally decrease. Similarly, continual addition of fecal material to the stream system during this baseflow period might be expected to increase or maintain fecal coliform concentrations in stream bottom sediments, but concentrations in sediments have been shown to decrease through the winter as well (Kidd, 1989).

Although continual vigilance is certainly warranted in preventing exfiltration from sewer pipes and in preventing and repairing cross connections between sewer and storm water pipes, available data clearly eliminate piped sewer systems as significant sources of fecal coliform in Anchorage streams.

### 4.1.2 On-Site Sewerage Systems

Strict regulation by the MOA and historic data, including a number of specially focused investigations, have generally eliminated on-site wastewater systems as widespread sources of fecal coliform in streams:

- On-site sewerage systems in the MOA are typically comprised of septic tanks and drainfields. Canter and Knox (1985), summarize national literature showing that pathogens (including fecal bacteria) are typically completely removed from household wastewater at depths of as little as 3 feet below well designed leachfields. Successful, on-site designs, however, are based upon matching sound design criteria to specific site constraints – including consideration for excessively low (or high) soil permeability, shallow impervious soils or broken bedrock, steep slopes, a shallow ground water table, and lot size (Metcalf & Eddy, Inc., 1991). The MOA regulates all on-site drainfield design and installation and addresses each of these constraints in its design criteria (Anchorage Municipal Code, 15.65). Given the nationally-recognized effectiveness of drainfield systems at removing fecal coliform, and the enforcement of appropriate designs for these type of systems implemented across the MOA, widespread contribution of fecal coliform from these systems seems unlikely.
- The MOA has monitored shallow ground water across the MOA corporate area specifically to assess the impact of on-site systems on shallow ground water and local streams (DHHS, 1986a; Montgomery and Ott, 1989). Results of the monitoring program revealed probable impacts on shallow ground water, specifically nitrate concentrations slightly elevated above background levels. However, data showed very little impact on shallow ground water from fecal coliform, with only 4 to 8 percent of all functional wells sampled in the study annually reporting one or more positive results for this pollutant (DHHS, 2000; MOA, 1992b).

  In instances where fecal coliform were identified in shallow ground water samples, observed concentrations were typically quite small (usually $10^1$ to $10^2$ col/100 ml). Wells with positive results were also commonly related to poor well construction, localized high-permeability soils, or ground water flows focused by locally complex glacial landforms. Results of more detailed studies of shallow ground water impacts from on-site septic systems further suggested that, over larger areas, observed impacts were generally relatively slight, and that areas of more severe impacts were infrequent and highly localized (DHHS, 2000; DHHS, 1990).

In a more recent investigation, the USGS (Frenzel and Couvillion, 2002) suggests a difference does exist in stream fecal coliform concentrations between areas using piped sewer systems (higher contaminant concentrations observed) and on-site drainfield systems (lower concentrations observed). However, investigators stated this observation did not account for obvious confounding factors such as landuse density, landcover, and storm water drainage system characteristics, and did not offer any singular interpretation of the observed differences in concentrations. In any event, the USGS analysis and available MOA data do not support an interpretation of the widespread use of on-site systems within the MOA as a significant contributor of fecal coliform to local streams.

- As noted earlier, the detailed analysis performed by the MOA in 1985 and 1986 of 184 suspected fecal coliform sources along Fish, Chester, and Campbell Creeks revealed very few human fecal contaminant point sources (two confirmed sewer pipe cross connections), and none attributable to surface or subsurface discharges from on-site systems. In fact, with the exception of the cross connections already noted and a few instances of isolated human fecal wastes from vagrants residing in or passing through riparian zones, every instance of significant contamination reported under this investigation was ascribed to a domestic or wild animal source (DHHS, 1987a).
- As for piped sewer systems, the seasonal periodicity of observed stream fecal coliform exceedances does not support the presence of a significant and persistent winter fecal coliform source such as might be produced from on-site systems. Similar to effects from a piped sewer system source, one would certainly expect winter fecal coliform concentrations to remain elevated if a significant, seasonally-uniform pollutant load was in fact being discharged from on-site systems. Since winter concentrations drop dramatically to near background levels for most streams in areas served predominantly by on-site systems, a significant contribution of fecal contaminants from these systems does not seem likely.

Based on analysis of a wide range of available data, on-site systems are clearly not implicated as primary sources to the fecal coliform problem in Anchorage streams. Fecal contaminants from these sources carried in shallow ground water do not appear to be a widespread or significant source of fecal contamination in local streams. Similarly, the results of detailed investigations and MOA inspections over the years do not support an interpretation of on-site systems as a ubiquitous source of contamination in surface storm runoff. However, some evidence does exist that, although likely of relatively low magnitude, some potential for transport of contamination from on-site systems to streams may exist as a result of inadequate design consideration of locally complex surface geology.

### 4.1.3 Street Sediments

Nationwide, street sediments and wastes have long been cited as sources of fecal coliform (Kobriger and Geinopolos, 1984; Dupuis, et. al., 1985; Sartor and Boyd, 1972; Barrett et. al., 1993). Its also true that fecal coliform contaminants have certainly been observed in storm water runoff from Anchorage streets (MOA, 1992a, Parts 1 and 2). In addition, the function particulates have as adsorption and protective sites for fecal coliform underscores the important role street sediments play in transporting coliform pollutants in storm water. However, recent investigations by the MOA to quantify fecal coliform in street sediments showed, by and large, that the street wastes themselves are not a significant source of fecal coliform:

- Sediments on Anchorage streets could represent a significant contaminant source simply because of the very large quantities of street dirt that are seasonally present on local streets (Wheaton et.al., 1997). The fact of preferential adsorption of fecal coliform to fine-grain particles, combined with the increased mobility of these finer particles (WMP, 1999a), further focuses a need to clarify relationships between fecal coliform and street sediments in Anchorage. To quantify these relationships, the MOA performed detailed sampling and analysis of sweepings and associated pollutant loading for Anchorage urban streets and trails (WMP, 2001a, b). Results suggest that fecal coliform load on sediments from Anchorage streets and trails is extremely low, with median values less than $1 \times 10^1$ most probable number per gram of sediment (WMP, 2001d). National data suggests preferential adsorption may increase concentrations in the smaller size fraction (particles less than 100 μm in diameter) by 2 to 42 percent (Kobringer and Geinopolos, 1984). The preferential adsorption to fine particulates and the mobility of the fine particle fraction in storm water runoff may in part—along with drying and exposure to sunlight—explain the low coliform count observed in Anchorage sampled street sediments despite obvious storm water transport of coliform into streets from adjacent contaminant sources. Even multiplying observed coliform concentrations by a factor of 1.5 to account for preferential adsorption to, and mobility of, fine particles, measured values of these contaminants on street sediments would still be several orders of magnitude lower than that of bottom sediments sampled from local Anchorage streams. Observations made during Anchorage street sediment sampling also suggest that animals do not defecate, and fecal material is generally not present, directly on street, sidewalk, or trail surfaces. However, several high concentration outliers in street sediment samples did appear related to poor curbside trash collection practices (i.e., broken and scattered plastic garbage bags).
- Although conclusions are tentative due to a very small sample set, some recent street snowmelt runoff sampling in Anchorage also suggests street sediments are a relatively minor contributor of fecal contaminants to storm water. Street runoff samples collected early in the snowmelt period (when the only meltwater was from snow melting directly from street surfaces) showed relatively low coliform concentrations (on the order of $1 \times 10^2$ col/100 ml). However, as snow melting from residential yards began to contribute runoff to the total flows along streets, concentrations in street runoff rose about an order of magnitude (WMP, 2002a, b). The increase in fecal coliform concentrations, coincident with the beginning of yard runoff, suggests a substantially smaller source loading on street surfaces than on adjacent residential yards.

Street sediment sampling data suggest that these sediments in Anchorage are not significant *direct* sources of the fecal coliform contamination in Anchorage streams. However, street sediments do play a vital role in how Anchorage urban fecal contamination is transported in storm water runoff. As noted, sediments provide important adsorption sites for fecal contaminants. Contaminants generated at off-street sources and transported to street drainage systems find a protective transport mechanism in the street sediments, particularly the fine particle fraction. Adsorption to the settleable street solids also plays a critical role in the unwelcome enhancement of the effects of in-stream coliform sedimentation and re-suspension. This can be particularly important where the energetic flows from curb and gutter and piped drainage systems increase the particulate carrying capacity of urban storm water flows. Thus, even although the street sediment itself may not be a source of fecal contaminants, control of street sediments (and particularly the fine-grain fraction) will be an important element in the overall control of fecal coliform concentrations in Anchorage streams.

### 4.1.4 Storm Drain Coliform Incubation

Fecal coliform bacteria excreted by warm-blooded animals have been shown to remain viable for prolonged periods of time and even propagate in suitable environments. Dark, moist, warm, organic-rich environments are most conducive to fecal coliform viability outside the originating host animals. Storm sewer systems, in general, can readily meet most of these conditions and, in the continental United States, a number of investigators have shown that fecal coliform bacteria can thrive and propagate in sediments deposited within storm sewer drainage systems (CWP, 2000). However, although some local conditions are similar to those reported in these national studies, short sediment detention times and low ground temperatures typical of Anchorage systems are not likely to support significant growth of fecal coliform bacteria within the MOA's piped storm systems. In general, available data suggests propagation of fecal coliform bacteria in storm drain systems is not a significant contributor to seasonal elevations in fecal coliform concentrations in Anchorage's stream waters:

- Much of those portions of Anchorage served by piped storm water drainage systems has been built on lowland wetlands. As a result, about two-thirds of Anchorage storm drain pipes capture shallow ground water and discharge these flows through the pipe systems to local streams. Dry weather flows from Anchorage storm drains average about 60 gallons per minute, and form a substantial fraction of the baseflow of urban streams during winter months (MOA, 1992a). Yet, despite this flow contribution from the pipe systems, winter stream fecal coliform concentrations measured in sampling programs performed over the years have been consistently low at about $1x10^1$ to $2x10^2$ col/100 ml (WMP, 2002b; USACE, 1979a, b; MOA, 1992a; DHHS, 1993)
- Although data is limited, sampling of baseflow directly from Anchorage piped storm drainage systems has also shown relatively low fecal coliform concentrations, with median values in one recent study at about $2x10^2$ col/100 ml (WMP, 2002a).
- Incubation of fecal coliform within Anchorage storm drain pipes is likely to be limited by relatively short sediment detention times and low ground temperatures common to local systems. Both settlement and scouring of storm water-transported sediments appears to occur within Anchorage piped drainage systems (WMP, 2002a). However, very few pipe networks have an annual net gain in trapped sediments sufficient to significantly impede hydraulic function or require maintenance. Rather, settlement of particulates seems to occur with a complex periodicity, but with sediments commonly subject to both settlement and re-suspension over the span of just a single storm event. Thus, sediment detention times in Anchorage storm drain pipes appear to be quite short, with the bulk of the sediment that enters a storm drain pipe during one spring and summer season certainly being flushed from that pipe by the end of the rainy season. That is, although sediments clearly seem to settle within the pipe systems, intermittent scour events appear

to rapidly remove these sediments, resulting in a net seasonal balance between sediments entering and flushed from the systems. Scouring (periodically reducing the total number of bacteria present) and short detention times (limiting the total time available for settled bacteria to grow) will significantly decrease the effects of any coliform propagation that does occur within the pipe systems.

- Ultimately, however, ground temperatures in Anchorage may be an even more important limiting factor to incubation of fecal coliform in Anchorage storm drain pipes. The median shallow ground water temperature in Anchorage is 39°F (Glass, 1999), or about the temperature that the EPA recommends as a preservation temperature for fecal coliform samples (USEPA, 1997).

In summary, abundant winter stream sampling data preclude storm pipe systems as significant widespread contributors of fecal coliform to winter stream waters. Similarly, analysis of more limited data suggests that short detention times resulting from rapidly shifting episodes of settlement and scour, combined with low ground temperatures, significantly limits the degree to which incubation of fecal coliform occurs within Anchorage's piped storm water drainage systems during the summer months.

Nevertheless, although piped systems are not thought to generally act as significant contributors to the fecal coliform problem observed in Anchorage streams, impacts are still locally possible. For example, local water quality sedimentation basins or grit settlement chambers may promote temperatures and detention times sufficient to support bacterial growth. Where poor design or improper maintenance allows periodic scour of collected sediments, these devices could intermittently increase fecal coliform loading in storm water flows entering streams. Fortunately, these localized conditions can be virtually eliminated with the use of effective flood bypass devices (e.g., side-discharge bypass weirs), multi-cell water quality treatment basins having engineered wetlands or other filtration technology between cells, and properly scheduled device maintenance.

## 4.2 SIGNIFICANT SOURCE CONTRIBUTORS

Data available from years of investigations in Anchorage do not support dry weather sources for the elevated fecal coliform concentrations observed in local streams. Although incorporation of bottom sediment or local sporadic riparian zone contamination may yield brief spikes in stream fecal coliform, generally winter concentrations of these pollutants are uniformly low. Low winter concentrations tend to exclude any dry-weather source, or continuous source (such as human sewage systems, piped or on-site), as causes of the exceedances that are actually observed in Anchorage streams. Rapid drops in stream fecal coliform concentrations in summer non-flood flow periods also support this conclusion.

Conversely, patterns in elevated fecal coliform concentrations in Anchorage receiving waters imply surface sources for these contaminants, ones that are significantly responsive to storm water runoff and stream flood flows. It should not be surprising, in this light, that most Anchorage investigations to date have confirmed animal wastes, both domestic and wild, as sources of elevated concentrations of fecal coliform contaminants seen in Anchorage streams. Although these investigations have occasionally identified continuous (as opposed to episodic, storm water-driven) point contaminant sources as causes of stream fecal contamination, these types of sources have been rare and localized, and have been repaired in every instance. On the other hand, the widespread occurrence and exposure of domestic and wild animal wastes evidenced by all past investigations is consistent with the conceptual model of storm water and stream transport mechanisms for fecal coliform presented in this document.

The evidence for animal wastes as the predominant source of fecal contaminants in streams is so compelling that this information becomes less useful than information about the distribution of these wastes and their association with specific landuses. Knowing distributions of particular animal sources is obviously important in assessing specific risks that might be related to a particular animal or group of animals. However, identifying distribution of animal sources relative to landuses is important because it can lead to a better understanding of storm water mobilization processes and ultimately to practicable means of controlling the contaminant problem. To help structure discussion of sources in context with these issues, animal sources have been grouped into four primary categories relative to a broad classification of Anchorage landuses: domestic animals in urban landscapes, domestic animals in rural landscapes, domestic animals in animal husbandry landuses, and wild and domestic animals in riparian areas.

### *4.1.5 Domestic Animals in Urban Landscapes*

Fecal coliform loading is high in storm water runoff from landscaped areas in densely urbanized Anchorage watersheds, particularly those drained by curb and gutter systems. Storm water runoff and pollutant mobilization processes and timing at these sources is subtle and complex, but play a critical role in how contaminants are transported and preserved in Anchorage drainage systems and steams:

- A broad range of MOA studies (WMP, 2002a; USACE, 1979a, b) show that fecal coliform loading in storm water runoff from highly urbanized residential areas is elevated, typically ranging from $10^2$ to $10^3$ col/100 ml during snowmelt events and $10^3$ to $10^4$ col/100 ml throughout most of the rainy season. Although other urban landuses and practices undoubtedly generate fecal contaminants (most likely related to exposed refuse containers and roof drainage carrying bird feces), domestic animals in residential areas are expected to be a predominant urban source. The fecal material exposed to storm water runoff in these areas is substantially related to pets (dogs and cats). It is also important to note that at Anchorage a climate element also plays a role in seasonal fecal material loading on residential (and other) landuses. As noted earlier (Part 4), cold winter temperatures, low insolation, and resulting snow buildup can tend to yield larger, season-long accumulations of fecal wastes from pets (as well as from wild animals).
- Observation of small-scale storm water runoff processes at residential basins suggests fecal contaminants from animal wastes are carried in subtle, low energy sheet flows from lawn surfaces, driveways, and roofs into adjacent street gutters (during both snowmelt and rainfall runoff events). These processes in highly urbanized Anchorage areas are exacerbated by the typical, close proximity of the pollutant-generating surfaces to streets (as a result of small lot sizes and driveway and lawn locations at streetside). The MOA also does not regulate surface storm water discharging into MOA rights-of-way so that there is an ensuing tendency for drainage from these surfaces to be directed, uncontrolled, into the street gutters. Finally, although sheet flow from yards and

driveways is rarely sufficient to carry suspended sediment, fine particulates remaining in street gutters provide protective adsorption sites for bacteria originating in the yards. Now adsorbed to particulates, the fecal contaminants are protected and significantly more subject to settlement (and later re-suspension) processes in stream channels.

### 4.1.6 Domestic Animals in Rural Landscapes

Little data exists quantifying fecal coliform concentrations in storm water from rural residential areas served by ditched storm drainage systems. However, the data that does exist suggests that total load delivered to streams in storm water may be substantially less for these areas than for more densely urbanized areas:

- Limited data suggests that precipitation-driven runoff from MOA rural urbanized areas served by ditched drainage systems occurs much less frequently than for residential areas with curb and gutter drainage (MOA, 1992a, b). Significant storm water runoff is expected from these rural ditched areas only during snowmelt runoff when the ground is frozen (USACE, 1979b), and in the late fall rainfall runoff period when antecedant soil moisture is very high (WMP, 2001d; WMP, 2002a). As a result of the reduced hydraulic load and given a similar source pollutant load on adjacent landuses, the total fecal coliform pollutant load transported in storm water to local streams in rural areas will be reduced relative to that from more urbanized areas.
- Anchorage rural landuses are typically reflected in larger lot sizes, a larger fraction of undeveloped (naturally vegetated) land, a reduced fraction of landscaped (lawn) areas, and reduced direct connection of roof, driveway, and lawn surfaces to the storm water drainage network (WMP, 2003a; WMP, 2002a, b). As a result, on a unit watershed basis, the pollutant load is reduced due to effects of lower landuse densities, and pollutant washoff is reduced through the (mostly serendipitous) effects of on-site detention, infiltration, and filtration. Rural landuses also do not typically include widespread agricultural industry, so that pollutant generators are generally otherwise similar to those at more urban Anchorage settings (i.e., pets, exposed refuse, and wild animals). The net effect is that Anchorage rural areas generate lower fecal coliform concentrations in storm water runoff.

Fecal wastes from domestic animals (mostly cats and dogs) provide a substantial contaminant source in rural areas as they do in more urban Anchorage areas. As a result, storm water from these landuses is subject to increased potential of fecal contamination. Still, given actual presence of the general rural conditions as defined above (larger lots, increased fraction of undeveloped land, ditched storm drainage), impacts from these areas relative to similar impacts from densely urbanized areas is expected to be substantially less for all storm runoff events, and certainly so for rainfall runoff events.

However, it should also be noted a ‘rural’ condition (as defined here) can no longer be ascribed to a particular Anchorage land development simply on the basis of a suburban location in the MOA. ‘Rural’ development within the MOA increasingly incorporates all the land development practices of more densely urbanized areas, including decreased lot size, reduced land left undeveloped (naturally vegetated), and greatly increased on-site lawned and impervious surfaces (including immense driveways) draining directly to community piped storm water drainage systems. Under these conditions, current ‘rural’ developments may affect an *increase* in fecal contaminant loading over their lowland urban counterparts, because many of these new development sites are located on steeply sloping surfaces underlain by low-permeability subgrade soils in higher precipitation areas—all leading to greatly increased potential for pollutant washoff.

### 4.1.7 Domestic Animals in Animal Husbandry Landuses

There is essentially no large-scale agricultural or livestock industry within the MOA (with the exception of several horticultural businesses). As a result, these landuses represent a relatively insignificant factor in the fecal contamination of Anchorage's streams. However, investigations of sources of fecal coliform contamination along Anchorage's streams have shown that private and public kennels, stables, outdoor zoos, and other livestock holding areas have frequently been responsible for significant point source impact on adjacent streams:

- Washoff of fecal wastes originating from animal husbandry operations has been recognized as a significant contributor to Anchorage stream contamination for nearly 20 years (Rundquist and Bandt, 1987; DHHS, 1986b; 1987a). A comprehensive investigation conducted between 1985 and 1986 of 184 potential sources of fecal contamination on various Anchorage streams identified 51 sites (or about 28 percent of the original number) with a high potential as actual sources of stream pollution (UAF, 1987; DHHS, 1987a). Of these 51 sites, 17 (or about a third of the sites identified as pollutant sources) were determined not to be significant sources after all. Of the remaining 34 fecal contaminant sources, about 67 percent were assigned to domestic animals and a significant 24 percent were associated with horse stables, dog kennels, and a local zoo.
- The MOA Animal Care and Control Center estimates that the MOA is currently home to approximately 50,900 pet dogs alone, generating over 38,000 pounds of feces every day. Horses, although much smaller in total population within the MOA, produce manure at a slightly greater rate—about 50 pounds per day per 1,000 pounds of body weight (USDA, 1975). Although the MOA does carry an ordinance that requires dog owners to remove and dispose of these wastes, enforcement over such a large domestic animal population is limited in its practicability. More to the point of this document, there are no specific MOA storm water runoff controls or inspections for animal pens of any type (either stables or kennels), other than a minimum stream setback (of questionable effectiveness) of 25 feet.

As a result, most of these types of facilities are not addressed (from a storm water runoff perspective) unless they become sufficiently noisome to neighbors to be reported. However, by sheer numbers alone, its seems clear that dog runs, kennels, and stables are significant sources of fecal contaminants. Although all dog runs are likely significant sources of fecal contamination in Anchorage streams as a result of a common exposure to precipitation and surface runoff, larger kennels and stables may increase potential for fecal matter transport in runoff as a result of concentrated number of animals, high rate of waste production, and purposeful design to integrate and discharge surface runoff away from the facilities.

### 4.1.8 Wild and Domestic Animals in Riparian Areas

The MOA occupies a narrow mountainous peninsula surrounded by water on three sides. Urbanized areas tend to be located at the base of the mountains along the perimeter of the peninsula. As a result, these urban areas are crossed by hundreds of small streams ranging in size from small rivers to rivulets with flows just sufficient to maintain active channels. MOA investigators have identified and mapped in detail over 46 major stream features, and scores of small tributaries, just within the more urbanized areas of the MOA alone (WMP, 2001c, WMP, 2002b). In addition to an obvious function as floodways, these streams provide important corridors and refuges for seasonal migrations either of local wild animals moving from the interior highlands to the surrounding lowlands, or of migratory birds nesting or resting along the riparian lowlands. Anchorage riparian zones and streams are home to a myriad of other shore and land birds as well, all of which also directly contribute fecal material to streams. These areas are equally important to the human residents of Anchorage, with the many trails and parks facilities maintained by state, federal, and MOA agencies preferentially located within or routed through stream riparian zones.

Unfortunately, impacts upon Anchororage's riparian areas are growing as urbanized areas expand. As developable land with the MOA decreases, urban encroachment upon the remaining riparian zones is reducing total corridor area and creating discontinuity in migratory pathways between seasonal alpine and lowland habitats. In addition, for many of the small tributaries, development means extreme channel modification and loss of effective adjacent vegetative buffers. These urban effects compress all of the riparian zone users within a smaller and smaller area, significantly increasing potential for impacts to streams from fecal contamination:

- Wild animals represent a significant source of fecal contamination to Anchorage streams, particularly where these animals' natural migratory habitat along riparian zones is encroached by urban development. Although not all MOA wild animal populations have been precisely enumerated, even the rough numbers available are still illustrative in terms of the potential magnitude of contribution of fecal material from these animals. The Alaska Department of Fish and Game (ADF&G) has estimated that the Anchorage Bowl alone is home to about a dozen wolves, 40 black bears, 5 brown bears, 150 beaver, over 200 year-round moose (increasing to an over-wintering population of near 1,000), 15 lynx, an unknown but stable population of fox and coyote, thousands of snowshow hares, hundreds of feral rabbits, and a quite visible population of porcupines (ADF&G, 2000). These populations of larger animals are accompanied by an abundance of other smaller mammals including squirrels, voles, shrews, bats, muskrat, mink, marten, and otter. Most of the larger animals may pass near or within open water on a daily basis, seasonally may continuously forage near or in the streams themselves (e.g., the brown bear during salmon runs), and of course some—like the beaver and muskrat—may live almost continuously within or along the margin of the streams. Impacts from the many small animals within a riparian zone are also not trivial when considered cumulatively. For example, the 1 or 2 pounds of fecal matter contributed per year by just one shrew may be small, but when multiplied by hundreds of shrews, volumes can become staggeringly large. Impacts from stable populations will also, of course, increase as animals are constrained to seasonally live within or pass through ever-narrowing urban riparian zones.

- A variety of waterfowl also thrive in riparian areas and wetlands within the MOA, including particularly large populations of geese and ducks. The riparian areas and wetlands within Anchorage provide nesting grounds for these birds, but park lawns and other large landscaped areas are also attractive to the geese. This is particularly true where these areas adjoin open water because of the abundance of high-protein, new-growth grass preferred by the wildfowl. In 1999, ADF&G estimated that about 4,600 geese nested in Anchorage (ADF&G, 2000). Since then, these summer migratory populations have declined substantially but still remain at about 1,500 birds. However, even at the reduced population, this summer migration still represents a feces production rate within the riparian zone of about 4,000 pounds per day.
- The Anchorage Bowl is also the permanent home of about 3,000 ducks that choose to over-winter in open stream water maintained by relatively warm ground water discharges. However, because of the much smaller body weight, the feces contribution represented by this duck population—about 100 pounds per day—is much smaller than that of a similar goose population. Still, the winter duck population is in addition to summer migratory birds of an unknown number, but large enough to permit harvesting about a thousand ducks annually at the Anchorage Coastal Wildlife Refuge.
- Riparian zones are preferred areas for the location of parks and trails. The MOA maintains 196 parks (including two public golf courses and five off-leash dog parks), 128 miles of paved bike trails, and 157 miles of unpaved trails. These trail and park systems are heavily used by Anchorage residents (and their pets). In 1999, reservations for picnic sites within MOA parks accounted for requests from 65,000 families (MOA, 2002b). A use poll conducted along one Anchorage creek-aligned trail counted as many as 2,000 trail users per day in the summer and a range of 100 to 350 users per day in the winter (MOA, 2002a). Parks recently established by the MOA are enormously popular—and are all located immediately adjacent to receiving waters. Although natural vegetation buffers between trails and streams can effectively reduce mobility of pet fecal material from trailways and parks (Bohn and Buckhouse, 1985, p 96), separation distances between streams and trails is not currently specified or enforced by the MOA. Similarly, stream setback criteria for park landscaping is also not established.

### 4.1.9 Other Potential Contaminant Sources

Anchorage data clearly implicates fecal contaminants that are mobile in storm water as the most probable sources of the observed fecal coliform impacts to local streams. Analysis of that same database suggests that these fecal contaminants predominantly originate from pets, livestock, and wildlife. However, limited data also suggests an additional source, exposed refuse, may be a final major contributor of fecal contaminants. Although data is currently too limited to determine the actual magnitude of this contribution, it is important to address this source, considering its human origin and the clear potential for transport in storm water:

- Although not sufficient to be compelling, available data suggesting refuse as a fecal contaminant source in storm water is at least worthy of further consideration. Recent sampling of street sediments revealed a tentative association of residential refuse with outlier values of fecal contamination measured in the sediment samples (WMP, 2001a). In Anchorage, curbside refuse collection is common for residential areas, and required by

> MOA code for highly urbanized areas. Although individual practices vary, it is not unusual for residents to set out the weekly garbage in otherwise unprotected plastic bags the day before pickup. Under these conditions, refuse can easily become exposed to storm water mobilization if the bags are torn either incidental to their exposed curbside location, or by foraging dogs and cats. It is also not uncommon for poor dumpster practices at multifamily residences and commercial buildings to lead to overfilling and exposure of wastes to precipitation, despite requirements for dumpster covers.

Although available data suggests that widespread contamination of street sediment does not occur from these sources, neither do the known fecal contaminants washed off residential lawns appear to contaminant the residual sediments present on the street. Despite this lack of street sediment contamination, coliform are known to be transported from yards and through street gutters and storm drain pipe systems. This might, in part, be explained by the fact that removal of street sediments in storm water runoff from Anchorage streets is also known to strongly favor transport of fine grain sediments (Wheaton et.al., 1997), which are also favored as adsorptive sites by coliform bacteria. Thus, coliform bacteria originating from adjacent landuses and carried by storm water into the street gutters, are mixed with and adsorbed to the fine particles entrained from the gutters by the storm flow, and are ultimately removed along with the fine sediment from the street in the runoff. Along with die-off resulting from exposure of street sediments to drying and strong sunlight, this preferential adsorption and mobilization might, in effect, minimize coliform contamination of the sediments remaining behind in street gutter pans and explain the low fecal coliform concentrations measured in MOA sampling of these sediments.

Given this scenario, the consistently low fecal coliform concentrations measured in MOA street sediments do not necessarily eliminate exposed refuse as an important source of fecal contaminants. That is, contaminants from these sources might still be released, but pass completely through the gutters during each storm runoff event just as might occur for contaminants from the adjacent lawn surfaces. Considering the uncertainty in the data and the potential risk of a human contaminant origin (and the relative ease of control), this source should not be excluded until additional data is collected.

# PART 5 IMPLICATIONS FOR FECAL COLIFORM MANAGEMENT IN THE MOA

The preceding analysis of source and transport processes for fecal coliform in Anchorage streams provides an important foundation from which to identify effective and practical controls for these pollutants. In the heat of addressing the health risk represented by a pollutant, it is often forgotten that mitigating that risk will cost money and a commitment of effort. Ultimately, the willingness (or ability) to pay must be balanced against the costs to incrementally reduce the risk. This balance can only be struck when not only the risk, but also the range of control options and their effectiveness and costs, are understood. At the least, some reasonable assurance of the eventual effectiveness of control options will be essential to mobilizing the community to any action at all. In this sense, the source and transport model presented in this document not only supports analysis of risk, but also provides a basis for making important management decisions for controlling the risk.

In this same context, once controls are selected, it will be equally important to assess installed controls for adequacy of function. That is, once put in place, how well are the controls working to reduce the impact of fecal coliform contaminants on Anchorage's streams? A monitoring approach that yields too many false negatives (i.e., a conclusion that the controls are working when really they are not) or false positives (i.e., a conclusion that the controls are not working when really they are) will cost the community, either in unnecessary additional control money spent or in moneys expended to no real benefit (or both). Thus, an effective monitoring program is also essential to a responsible and effective pollutant management program. Again, the source and transport model presented in this document can help to guide development of monitoring tools that will ensure that the community is 'getting its moneys worth' in terms of applied controls.

## 5.1 IMPLICATIONS FOR CONTROLS

Effective control options for fecal coliform are strongly linked to the characteristics of sources, local storm water drainage systems, and the streams themselves. Best management practices (BMPs) should focus on 'leverage' points within each of these systems. In this regard, implementation of practices to control contaminant exposure, mobilization, and adsorption to fine particulates, and control of new, and restoration of old, stream modifications will be critical to successful mitigation of fecal coliform contaminants in Anchorage's streams.

### *5.1.1 Contaminant Exposure*

As for most contaminant control strategies, one of the most effective for the fecal coliform problem at Anchorge will be in reducing exposure of fecal material to precipitation and storm water runoff in the first place. Even more fortunate is that, besides being the most effective type of control; is that it is also the cheapest. Innumerable specific controls can be created to achieve this objective, but a few of the most critical include:

- **Garbage Collection BMPs.** Develop and implement improved practices for residential garbage pickup and commercial and multi-family dumpster practices that will reduce exposure to storm water. Single-family curbside pickup practices should specifically address curb setback distance (to prevent upset by snow plowing or traffic) and enforce use of containers resistant to spillage and pet foraging. Dumpster requirements should specifically address minimum capacity to reasonably prevent overfilling, and consider requirements for shed covers to minimize dumpster exposure to storm water. Although the magnitude of this potential source remains uncertain, the apparent risk of mobilizing substantial human-specific pathogens and the relative ease of control supports implementation of this BMP in any event.

- **On-Site Systems Inspections.** Anchorage's on-site systems criteria meet all critical elements in design of a properly functioning drainfield-type system. However, these criteria do not specifically address the impacts that highly isotropic surficial geology in Anchorage may have on focusing discharges from these systems. There is also no mechanism in place to review or inspect systems for proper functioning except at the time of property sale. Although available evidence shows that any impacts from on-site systems in Anchorage are not a source of widespread fecal contamination to local streams, aging systems and missed soil problems can certainly result in localized system failures and elevated risk for release of human-specific pathogens. Initial consideration of isotropic soils impacts and periodic performance inspections can significantly reduce these risks.
- **Itinerant Riparian Camping.** Non-point source human fecal contamination within undeveloped riparian zones has been reported only in association with vagrant camps. These sources have also typically been small, isolated, and usually effectively disconnected hydraulically from adjacent waterbodies. However, as larger, officially sanctioned camps are considered, both sewage and waste control from these sites will become more important.
- **Waterfowl Control.** Wildfowl, particularly geese, have been a considerable problem for Anchorage in the past and remain a significant direct contributor of fecal contaminants to local streams. Urban geese are particularly attracted to lawns, and these surfaces increase potential for mobilization of the resulting concentrations of bird feces. Policies to directly control geese populations should be actively supported by the MOA. In addition, large grassed lawnscapes, particularly near any receiving waters, should be actively discouraged and no lawns or landscaping (other than restorative) of any size should be permitted within stream setback buffers.
- **Riparian Corridor Protection.** Wildlife is an important and economically valuable resource to the Anchorage community. However, if the value of this resource is to be conserved without undue impact on the community, we must recognize the importance of riparian corridors to local wildlife and the impact that constricting those corridors has on all of us. In addition to an increase in the number of wildlife conflicts with urban residents (as well as loss of many other valuable greenbelt human uses), narrow and broken riparian corridors increasingly confine wildlife movement, foraging, and nesting to a zone in close proximity to streams. This proximity significantly increases the potential for fecal coliform contamination of local streams. Policy needs to be considered that addresses acquisition, establishment, and maintenance of *continuous* riparian (greenbelt) zones along *all* Anchorage streams, with widths set relative to stream size.

### 5.1.2 Contaminant Mobilization

With the exception of direct deposition in streams (mostly from wild animals), fecal material must be transported in runoff before it can enter and contaminate local streams. Minimizing mobilization of contaminants in storm water, therefore, is a primary objective. The closer to the source this particular type of control is applied, the easier and cheaper it will be to accomplish this. Although any technique applied anywhere along a storm water flow path that reduces the total runoff volume and flattens peak flow rates should be the objective of this type of control, the following are particularly important:

- **Animal Pen Runoff Controls.** Animal confinement areas of any size that are exposed to storm water runoff represent an extraordinarily large and widespread source of fecal contaminants. In addition, concentrated or large animal holding areas (for example dog kennels, outdoor zoos, and horse stables) represent very high potential for point source fecal contamination. Although the MOA code provides for enforcement of some controls (mostly in terms of cleanup) for animal fecal wastes, little enforcement is practicable given the huge pet population. Requirements for installation of effective storm water washoff controls specifically for animal pens, large or small, do not exist. However, implementation of storm water washoff controls for animal holding areas (particularly for dog runs, zoos, and stables) is practicable, easily installed on-site by most owners, and provide some opportunity for enforcement to be paid for by licensing or fines. In addition, requirements for effective stream setbacks and formally-designed storm water controls should be implemented for any holding areas for larger animals or for concentrations of animals.
- **Yard Runoff Retrofits.** In general, lawns in residential areas contribute significant fecal coliform, mostly from pets. Simple infiltration breaks along lawn edges and ends of paved driveways can be employed to significantly reduce not only the fecal coliform load, but the hydraulic load represented by runoff from lawn surfaces. These breaks are easy and inexpensive to install and, in fact, may consist of nothing much more than a specially designed flowerbed. However, although easily required for construction in new residential developments, requirements for retrofits at established residential areas will be harder to enforce. Nevertheless, implementation of these devices, along with animal pen runoff controls, might alone account for control of the bulk of fecal contaminant contributions to Anchorage streams.
- **Low Impact Development (LID) Practices.** Urbanization leads to drastic changes in the character of storm water runoff, dramatically increasing peak flow rates and total runoff volumes. These larger, more energetic urban flows readily mobilize fine street sediments (and adsorbed fecal coliform) and provide very large stream flood peaks perfect for initializing stream bottom sediment re-suspension. In the past, communities have attempted to control these flows at the end-of-pipe (EOP), but such controls are very expensive and not very effective. A new approach (LID) seeks to control the hydraulic problems where it is easiest and orders of magnitude cheaper—at each individual property. Implementation of these techniques should be encouraged for all new development for all landuses. Some retrofit using these techniques should also be required, particularly for large, impervious surface, commercial properties.

- **Street Drainage Design.** Street and storm water drainage system design offers many opportunities to reduce storm water impacts. Open, vegetated swales provide detention, infiltration, and filtration opportunities not available with piped systems. Although swales are not feasible in more densely urbanized areas, they offer more opportunities than would seem at first glance. For example, swales can be employed in 'headwater' (dead end, turn-around street segments) and might be feasible along low-volume residential streets through use of one-side-only sidewalks and parking. Reduced, impervious street surface with less parking and sidewalk surface also reduces total runoff volume. In addition to storm water value, these systems also provide increased opportunities for side-cast snow storage, reducing winter maintenance and hauling costs. Construction costs might also be reduced through greatly reduced curb and gutter and drainage pipe construction costs.
- **End-of-Pipe (EOP) Controls.** Control of urban hydraulics at the EOP is typically very expensive and of limited effectiveness. However, for highly developed areas, alternative LID practices might have only limited utility. Anchorage has additional opportunity, however, where natural wetlands and riparian zones still exist near the end of urban storm drainage networks. Wetlands provide huge detention and filtration capacity, mitigating not only hydraulic impacts but treating fine particulates (and adsorbed pollutants) as well. Unfortunately, these opportunities have been previously overlooked and storm water drainage systems have typically been routed through wetlands along ditches or pipe systems. Policy should be developed to actively conserve appropriate wetlands and undeveloped riparian zones for incorporation into Anchorage's storm drainage networks and to implement retrofit and use of these wetland features (after appropriate storm water pre-treatment) for storm water detention and treatment.

### 5.1.3 Contaminant Adsorption Processes

Fine particulates play a principal role in aggravating the fecal coliform problem in Anchorage streams. They provide protective sites for the adsorbed bacteria both during transport in storm water and within the streams. The seasonal settlement of the particulates in streams leads to accumulation of large stores of contaminants in stream bottom sediments. These stores are a critical factor in the extreme concentration of fecal coliform observed in streams as the fine sediments are later re-suspended in mid-summer flood flows. Control of sources of these fine particulates, then, can help to flatten the response of streams to storm water and flood flow mobilization of the particles. Potential controls include:

- **Street Sweeping Practices.** Correctly performed and timed street sweeping is a prime example of the value of source versus EOP controls. Street sweeping, the source control, removes 50 to 90 percent of all particulates from Anchorage road surfaces at a cost of less than 10 cents per pound of sediment swept up. Conversely, grit settling chambers, the EOP approach, costs closer to $10 per pound to remove only about 10 percent of the sediment that actually washes through the device. Given this return, it is very difficult to argue with implementing current street sweeping guidance recommendations.
- **Private Parking Sweeping Practices.** In highly urbanized areas, commercial roofs and parking areas account for a significant fraction of all landcover. Little or no storm water controls are currently required for these landuses. However, implementing current

parking lot guidance recommendations, including street sweeping and snow disposal practices, will significantly reduce hydraulic and pollutant impacts from these sources.

### *5.1.4 Stream Channel Modification*

Modifications along Anchorage stream channels, typically a combination of constrictive crossings and ditching and channel straightening, are a major factor in seasonal storage and re-suspension of fine particulates carrying fecal coliform contaminants. Ditching of stream channels promotes flood erosion and mobilizes additional fine particulates most suitable as sites for adsorption of fecal coliform. At the same time, broad, shallow channel cross sections promote low-flow settlement and accumulation of these fine sediments, along with their adsorbed fecal coliform contaminants. Conversely, natural channels transport suspended and wash sediment loads most efficiently through the stream system, minimizing sedimentation and erosion. Reconstruction of the worst channel conditions may be desirable, if expensive. In this regard, prevention is the best medicine—policies to protect natural channels and adjacent riparian zones for streams of *all* sizes will not only be cost-effective in controlling fecal coliforms, but will repay the community in large economic dividends in terms of other use benefits as well:

- **Stream Modification Prohibition.** Riparian zone encroachment and channel modification substantially alter stream geometry and hydraulic properties. As a result, erosion and sedimentation *both* increase, promoting the sedimentation and re-suspension processes that support extreme fecal coliform concentrations observed in Anchorage streams. Impacts are particularly severe along smaller, lower-order streams, where the very presence of the stream is often overlooked or where its functional value is considered insignificant due to small size (unfortunately, from a potential for hydraulic and pollutant impact, the opposite is often true). Until effective policy and guidance is established prohibiting natural channel modification and implementing meaningful stream setbacks and natural riparian zone conservation, conditions conducive for elevated fecal coliform concentrations in MOA streams will remain and expand.
- **Stream Restoration.** Currently, stream ditching, straightening, and armoring remains a common practice. Fifty percent or more of many highly urbanized Anchorage streams are ditched or piped. Ditching frequently results in straight, shallow, and broad channels. Public and private trails, roads and bridges have often been designed only with flood passage and economy in mind, resulting in overly narrow and constricting crossings. As a result, wherever a ditched stream channel is broken by a too-narrow crossing, flows tend to become impounded, creating perfect ‘settlement’ and ‘re-suspension’ chambers for coliform-laden fine sediments. Removal and restoration of all these features is mind-numbing to contemplate. However, identification and restoration of at least the worst offenders will be essential to reducing the fecal coliform impacts currently observed on some Anchorage streams.

## 5.2 IMPLICATIONS FOR MONITORING

Due to the extreme spatial and temporal variability in fecal coliform concentrations inherent across the whole system (including contaminant generation surfaces, storm water drainage networks, and streams), conventional water quality sampling is not likely to be able to resolve useful effects of controls except at great expense or with observation over the very long-term. Sampling effluent from the storm drainage systems themselves will not likely be a useful means of determining area-wide performance of controls. This is due to the extreme costs that would be required to resolve meaningful concentration representation across whole storm runoff events, given the extreme variability in landcover runoff, pipe response to that runoff, and drainage area to drainage area variability.

Given these constraints, measurement of control performance should be developed around the following three elements:

- **Short-Term (1- to 2-year interval) – Numbers of Installed Controls.** Measure control effectiveness solely through degree of success in reaching set goals for installation of specific numbers or qualities of selected controls.
- **Middle-Term (3-year interval) – Stream Bottom Sediment Sampling.** Measure control effectiveness through carefully designed sampling of seasonal variations in stream bottom sediments.
- **Long-Term (6-year interval) – Stream Water Quality Sampling.** Measure control effectiveness through application of carefully designed trend sampling of stream water quality.

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# Appendix A

# Annotated Bibliography

# FECAL COLIFORM IN ANCHORAGE STREAMS
# ANNOTATED BIBLIOGRAPHY
## (Local Studies)

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Key: S=Stream, L=Lake, B=Baseflow, SE=Storm Event, CE=Constructive Pond, OF=Outfall
MH=Manhole, MW=Monitoring Wells, SI=Source ID, OG=OGS

## FECAL COLIFORM IN ANCHORAGE STREAMS
## ANNOTATED BIBLIOGRAPHY
## (Local Studies)

| Number | Title | Date | Agency | Sampling Type |
|---|---|---|---|---|
| 20 | Fish and Chester Creek Pollution Source Investigation | 1985 | DHHS | OF, MH, CP, S |
| 21 | Quantity and Quality of Urban Runoff from the Chester Creek Basin. Water Resources Investigations Report 86-(draft copy). | 1985 | USGS | S |
| 22 | Eagle River Drainage Study | 1986 | DPW | NA |
| 23 | Surface Water Quality in Little Campbell Creek at the Alaska Zoo | 1986 | DHHS | SI, S, BF, SE |
| 24 | Anchorage Shallow Groundwater Monitoring Well Site Selection Study | 1986 | DHHS | MW |
| 25 | Lower Chester Creek Improvement Study. Project 84-E-34. | 1986 | DPW | NA |
| 26 | Investigative Study for Determining Pollution of Surface and Subsurface Water by On-Site Septic Systems | 1987 | DHHS | S, B, SE, MW |
| 27 | Oil and Grease Separator Performance Project Work Request No. 6 Final Report | 1987 | DHHS | OGS, SE |
| 28 | Sedimentation Pond Performance Final Report | 1987 | DHHS | CP, SE |
| 29 | Bacterial Pollution Source Investigation in Campbell, Chester, and Fish Creeks Final Report | 1987 | DHHS | SI, S, OF, MH |
| 30 | Little Campbell Creek 1987 Spring Breakup Monitoring | 1987 | DHHS | S, SE |
| 31 | Schematic Design Report for the Alaska Zoo Project | 1987 | DPW | NA |
| 32 | Review of a Consultant's Report on Septic System Contamination at Anchorage, Alaska, with Interpretations of Data | 1987 | DGGS | NA |
| 33 | Water Quality in the Great Land Alaska's Challenge | 1987 | UAF | NA |
| 34 | 18 AAC Water Quality Standards as Ammended Through July 3, 2003 | 1987 | ADEC | NA |
| 35 | Anchorage Rainfall / Runoff Study South Anchorage Hydrology Study | 1988 | DPW | SE, S |
| 36 | Spring Break-Up Flows in Anchorage Storm Drains | 1989 | DPW | S, SE |
| 37 | Water Quality Monitoring Program Annual Report | 1989 | DHHS | L, S, B, SE, MW |
| 38 | Winter Fecal Coliform Concentrations in Stream Sediments | 1989 | UAA | S |
| 39 | Seasonal Variation of Conductivity, Dissolved Oxygen, and Fecal Coliform Bacteria Levels in Campbell Creek, Anchorage, Alaska | 1989 | UAA | S, SE, B, SI |
| 40 | Evaluation of Fecal Coliform Levels Within The Municipality of Anchorage, AK | 1990 | DHHS | S, B, SE |
| 41 | Water Quality Monitoring Program: Appendix C DHHS Water Quality Database 1989/1990 | 1990 | DHHS | NA |
| 42 | Water Quality Monitoring Program: 1989/1990 Annual Report | 1990 | DHHS | S |

Key: S=Stream, L=Lake, B=Baseflow, SE=Storm Event, CE=Constructive Pond, OF=Outfall
MH=Manhole, MW=Monitoring Wells, SI=Source ID, OG=OGS

# FECAL COLIFORM IN ANCHORAGE STREAMS
# ANNOTATED BIBLIOGRAPHY
## (Local Studies)

| Number | Title | Date | Agency | Sampling Type |
|---|---|---|---|---|
| 43 | Hillstrand Pond Rehabilitation Study | 1991 | DPW | CP |
| 44 | 1992 NPDES Permit Application - Appendix B | 1992 | WMS | SE, S, SI |
| 45 | NPDES Permit Application Part 1 | 1992 | DPW | NA |
| 46 | NPDES Permit Application Part 1 Appendices | 1992 | DPW | NA |
| 47 | NPDES Permit Application Part 2 | 1992 | DPW | NA |
| 48 | Areawide Water Quality Monitoring Program 1988-1992 Interpretive Report | 1993 | DHHS | B, S, L |
| 49 | Waterbody Assessment - Chester Creek Drainage (Draft) | 1993 | USGS | SI |
| 50 | Waterbody Assessment - Campbell Creek Drainage (Draft) | 1994 | USGS | SI |
| 51 | Memo: Municipality of Anchorage Fecal Coliform Study Task 2: Collect and Review Existing Information | 1995 | MOA | SI |
| 52 | Waterbody Assessment - Fish Creek Drainage (Draft) | 1996 | USGS | SI |
| 53 | Ship Creek Water Quality Assessment | 1996 | ADEC | SI |
| 54 | Bacterial Monitoring Alternatives. Document No. WMP PMg96001 | 1996 | WMP | NA |
| 55 | Alaska's 1996 Water Quality Assessment Report: Clean Water Act Section 305(b) and 303(d) Submittal | 1996 | ADEC | NA |
| 56 | Anchorage Goose Management White Paper | 1997 | USFWS | NA |
| 57 | TDML for Fecal Coliform in Jewel Lake Anchorage, AK | 1997 | ADEC | L, SI |
| 58 | TDML For Fecal Coliform in Lakes Hood and Spenard, Anchorage, Alaska | 1997 | ADEC | L, SI |
| 59 | Draft Environmental Assessment of Canada Goose Population Management in Anchorage, AK | 1997 | USFWS | NA |
| 60 | Comments on Lake Hood and Spenard TMDL | 1997 | EPA | NA |
| 61 | Comments on Jewel Lake TMDL | 1997 | EPA | NA |
| 62 | Street Sediment Buildup Rates in Anchorage, Alaska | 1998 | WMS | NA |
| 63 | Concentrations of Fecal Coliform Bacteria in Creeks, Anchorage, Alaska, August and September 1998 | 1999 | USGS | S |
| 64 | Water-Quality Assessment of the Cook Inlet Basin, Alaska - Summary of Data Through 1997 | 1999 | USGS | S |
| 65 | Anchorage Climate Characteristics | 1999 | WMS | NA |
| 66 | Anchorage Bowl OGS Performance Modeling | 1999 | WMS | NA |

Key: S=Stream, L=Lake, B=Baseflow, SE=Storm Event, CE=Constructive Pond, OF=Outfall
MH=Manhole, MW=Monitoring Wells, SI=Source ID, OG=OGS

| **Number** | **Title** | **Date** | **Agency** | **Sampling Type** |
|---|---|---|---|---|
| 67 | An Exploration of Environmental Surrogates for Fecal Coliform Concentrations in Anchorage Recreational Waters | 2000 | APU | L,S |
| 68 | Street Sediments and Absorbed Pollutants: Design Report | 2000 | WMP | SI |
| 69 | Street Sediments and Absorbed Pollutants: Data Report | 2000 | WMP | SI |
| 70 | Anchorage Street Deicer and Snow Disposal Investigation: 2000 Data Report | 2000 | WMS | Meltwater |
| 71 | Local Wellhead and Aquifer Protection Study Phase II | 2000 | DHHS | NA |
| 72 | Results for Fecal Coliform Regulatory Assessment and Internet Search for Data on Fecal Coliform in Street Cleaning Materials | 2001 | HartCrowser | SI |
| 73 | Fecal Coliform in Street Sediments: 2001 Data Report | 2001 | WMS | SI |
| 74 | Street Sediment Impacts: Data Report | 2001 | WMS | SI |
| 75 | A Technical Approach for Fecal Coliform Bacteria TMDLs in Alaska | 2001 | Tetratech | NA |
| 76 | 2001 Street Sediment Data Report | 2001 | WMS | NA |
| 77 | Source Assessment of Fecal Coliform in Anchorage Storm Water: 2002 Data Report | 2002 | WMS | SE, SI, OF |
| 78 | Fecal-Indicator Bacteria In Streams Along A Gradient of Residential Development | 2002 | USGS | S |
| 79 | Development of Fecal Coliform TMDLs for Fish Creek, Furrow Creek, Little Campbell Creek, Little Rabbit Creek and Little Survival Creek, Alaska. Watershed Characterization Report. | 2002 | Tetratech | NA |
| 80 | Source Assessment of Fecal Coliform in Anchorage Storm Water: 2002 Data Report. | 2002 | WMP | |
| 81 | 2002 Annual Report NPDES Permit No. AKS05255-8 | 2003 | WMS | SE, S, SI |
| 82 | Total Maximum Daily Load (TMDL) for Fecal Coliform in the Waters of Fish Creek in Anchorage, Alaska | 2003 | ADEC | NA |
| 83 | Total Maximum Daily Load (TMDL) for Fecal Coliform in the Waters of Furrow Creek in Anchorage, Alaska | 2003 | ADEC | NA |
| 84 | Total Maximum Daily Load (TMDL) for Fecal Coliform in the Waters of Little Campbell Creek in Anchorage, Alaska | 2003 | ADEC | NA |
| 85 | Total Maximum Daily Load (TMDL) for Fecal Coliform in the Waters of Little Survival Creek in Anchorage, Alaska | 2003 | ADEC | NA |
| 86 | Total Maximum Daily Load (TMDL) for Fecal Coliform in the Waters of Little Rabbit Creek in Anchorage, Alaska | 2003 | ADEC | NA |

## FECAL COLIFORM IN ANCHORAGE STREAMS
## ANNOTATED BIBLIOGRAPHY
## (State and National Studies)

| Number | Title | Date | Agency |
|---|---|---|---|
| 1 | Winter Survival of Fecal Indicator Bacteria in Subarctic Alaskan River | Aug-72 | EPA |
| 2 | Prelimary Study of Comparative Winter Survival of Fecal Bacteria in Subarctic River | Aug-75 | EPA |
| 3 | Effect of Holding Temperature and Time on Total Coliform Density in Sewage Effluent Samples | Apr-78 | EPA |
| 4 | Alaska Water Quality Standards Regulations | May-97 | DEC |
| 5 | Water Quality in the Great Land Alaska's Challenge | 1987 | UAF |
| 6 | Health Effects of Swimmers and Nonpoint Source of Contaminated Water | 1991 | JH |
| 7 | Protocol for Developing Pathogen TMDLs | Jun-05 | EPA |